BENTON HARBOR POWER PLANT LIMNOLOGICAL STUDIES

PART XIII. COOK PLANT PREOPERATIONAL STUDIES 1972

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PREVIOUS PARTS OF THE REPORT SERIES RELATIVE TO THE DONALD C. COOK NUCLEAR STATION

Benton Harbor Power Plant Limnological Studies

Part I. General Studies. J. C. Ayers and J. C. K. Huang. April 1967. 31 p.

Part II. Studies of Local Winds and Alongshore Currents. J. C. Ayers, A. E. Strong, C. F. Powers, and R. Rossmann. December 1967. 45 p.

Part III. Some Effects of Power Plant Waste Heat on the Ecology of Lake Michigan. J. R. Krezoski. June 1969. 78 p.

Part IV. Cook Plant Preoperational Studies 1969. J. C. Ayers, R. F. Anderson, N. W. O'Hara, G. Kidd. March 1970. 92 p.

Part V. Winter Operations, March 1970. N. W. O'Hara, R. F. Anderson, W. L. Yocum, J. C. Ayers. April 1970. 17 p.

Part VI. *Pontoporeia affinis* (Crustacea, Amphipoda) as a Monitor of Radionuclides Released to Lake Michigan. C. C. Kidd. 1970. 71 p.

Part VII. Cook Plant Preoperational Studies 1970. J. C. Ayers, D. E. Arnold, R. F. Anderson, H. K. Soo. March 1971. 72 and 13 p.

Part VIII. Winter Operations 1970-1971. J. C. Ayers, N. W. O'Hara, W. L. Yocum. June 1971. 41 p.

Part IX. The Biological Survey of 10 July 1970. J. C. Ayers, W. L. Yocum, H. K. Soo, T. W. Bottrell, S. C. Mozley, L. C. Garcia. 1971. 72 p.

Part X. Cook Plant Preoperational Studies 1971. J. C. Ayers, H. K. Soo, W. L. Yocum. August 1972. 140 and 12 p.

Part XI. Winter Operations 1971-1972. J. C. Ayers, W. L. Yocum. September 1972. 26 p.

Part XII. Studies of the Fish Population Near the Donald C. Cook Nuclear Power Plant, 1972. D. J. Jude, T. W. Bottrell, J. A. Dorr III, T. J. Miller. March 1973. 115 p.

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INTRODUCTION

In Part VII (March 1971) of our report series relative to the Donald C. Cook Nuclear Power Station, the following report format was established:

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- A.3 Development of a Monitor for Phytoplankton
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C. THE ICE BARRIER AT THE COOK PLANT SITE

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This format remains applicable and in use. Different timing of incoming results requires that some parts of the format be reported at times different from the reporting of others. In addition, some of the parts will attain bulk sufficient to require separate reporting. In general this report constitutes an "annual report" of the year's activities.

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*A.10 is an addition to the annual report format.

A. COOK PLANT PREOPERATIONAL STUDIES 1972

A.1 *Recording of Local Water Temperatures*

John C. Ayers

Daily minimum and maximum water temperatures are collected by Indiana and Michigan personnel from an array of thermistors installed at the Cook Plant site and at the water treatment plants of Benton Harbor and St. Joseph. The Benton Harbor intake is 3,375 feet from shore and in 40 feet of depth; the St. Joseph intake is 1,490 feet from shore and in 19 feet of water.

The Cook Plant installation consists of a thermistor equipped submarine cable extending into the lake at the north edge of the plant property. Two of the five thermistors are located approximately 300 feet from shore; the rest are 2,500 feet from shore. At the 300 foot position the thermistors are held by subsurface floats at water depths of 2 feet and 4 feet; at the 2,500 foot position the thermistors are similarly held at water depths of 2, 12, and 17 feet.

The thermistors at the plant have had a record of varying degree of outage. The array was activated on 3 May 1972 but was taken out of service on 18 May when the cable broke at the junction box, apparently because the cable was rubbing against a float. Restored on 31 May, the thermistors at the 300 foot position were put out of commission during a lightning storm on 2 June and remained inoperable for the rest of the summer. The thermistors at the 2,500 foot position were out of order from 19 July through 23 July, and the one at 17 feet of depth proved irreparable and was out of action for the rest of the summer.

The system was removed for inspection and repair in October. Inspection showed that the solid conductor lead wires to the thermistors were broken,

presumably resulting from the flexing caused by wave action on the submerged floats. Lightning damage was not proved, but we have suggested that lightning protection be incorporated into the system that will be installed in the spring of 1973.

Water temperatures through March 1972 have been reported in Part X of the Cook Plant report series. Table 1 reports temperatures collected since April 1972.

Table 2 presents the daily natural temperature variations in their raw water from the records of the Benton Harbor and St. Joseph water filtration plants. These variations are the differences between the daily minima and maxima of raw water temperatures at the plants. The daily temperature variations at these plants have been grouped by 3°F increments of variation and by numbers of occurrences by days in the months of January through December for the years 1970, 1971, and 1972. The bottom row of the table, headed "2-Plant Monthly Fraction," gives the ratio of the numbers of days when the natural temperature variations of 3°F or more were recorded to the 2-plant number of total record days for the months and years involved.

Table 3 presents similar data from the thermistors at the 2 and 12 foot depths at the 2,500 foot position in the Cook Plant temperature sensing system. The bottom line of Table 3, headed "2-Depth Monthly Fraction," gives the ratio of the number of days when natural temperature variations of 3°F or more were recorded to the 2-depth number of total record days for the months and years involved.

Table 4 reduces the monthly fractions of Tables 2 and 3 to percentage of days in which the natural water temperature variations of 3°F or more were recorded in the Cook Plant Region.

Table 1. Daily minimum and maximum Lake Michigan water temperatures at the Cook Plant site and at the Benton Harbor (BH) and St. Joseph (SJ) water plant intakes. Whole degrees Fahrenheit. Note: Blank spaces indicate that no data were obtained.

	COOK PLANT										BH		SJ	
Offshore	300 Ft.				2500 Ft.						3375 Ft.		1490 Ft.	
Depth	2 Ft.		4 Ft.		2 Ft.		12 Ft.		17 Ft.		40 Ft.		19 Ft.	
							APRIL 1972							
DATE	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
1											36	37	34	37
2											36	38	35	36
3											38	39	36	38
4											37	38	36	40
5											37	40	37	38
6											39	39	37	38
7											37	38	38	41
8											37	37	37	38
9											37	40	37	38
10											40	41	38	38
11											39	41	38	43
12											39	40	39	43
13											40	43	39	43
14											40	42	42	44
15											40	41	41	43
16											41	42	42	43
17											40	43	42	43
18											43	45	42	45
19											44	45	45	45
20											43	45	42	45
21											43	44	42	42
22											44	45	42	43
23											45	46	43	44
24											46	46	43	48
25											44	45	44	45
26											44	45	44	46
27											46	47	42	46
28											44	45	42	45
29											43	44	44	44
30											43	44	44	45
MIN											36	37	34	36
MAX											46	47	45	48
AVE*											41	42	40	42

*Average temperature rounded to nearest whole degree Fahrenheit

Table 1, cont'd.

	COOK PLANT										BH		SJ	
Offshore	300 Ft.				2500 Ft.						3375 Ft.		1490 Ft.	
Depth	2 Ft.		4 Ft.		2 Ft.		12 Ft.		17 Ft.		40 Ft.		19 Ft.	
					MAY 1972									
DATE	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
1	OUT OF ORDER										44	47	43	45
2											47	47	45	47
3	45	48	47	48	45	47	45	47	45	45	47	47	45	46
4	45	46	46	52	45	48	47	52	46	48	46	47	45	47
5	45	47	45	48	45	53	45	47	45	53	46	47	45	46
6	47	51	46	48	47	52	47	50	47	51	46	48	46	49
7	46	47	46	49	46	49	46	49	46	49	47	49	45	48
8	45	48	44	46	45	48	45	48	47	48	45	47	45	46
9	44	49	44	46	45	48	45	47	45	49	45	46	45	46
10	43	54	42	44	43	59	43	48	43	53	46	47	45	47
11	47	58	42	44	45	58	42	47	47	57	46	46	45	47
12	45	50	41	46	42	50	43	47	42	50	45	45	45	47
13	45	48	43	47	46	48	43	46	46	48	46	47	47	48
14	46	47	46	49	46	48	45	48	46	48	48	50	48	49
15	46	49	46	47	46	48	45	48	46	49	50	51	49	49
16	46	50	45	47	46	50	46	49	46	47	50	51	49	50
17	47	50	46	47	47	50	47	49	48	54	49	50	49	50
18											48	49	49	49
19											46	47	45	49
20											45	46	44	49
21											45	47	48	50
22											46	47	45	49
23											45	49	44	48
24	OUT OF ORDER										45	47	44	46
25											45	45	43	46
26											44	45	43	44
27											43	44	43	46
28											45	48	45	50
29											48	52	49	55
30											53	56	54	57
31	47	53	47	52	49	52	47	52	49	52	50	56	48	55
MIN	43	46	41	44	42	47	42	46	42	45	43	44	43	44
MAX*	47	58	47	52	49	59	47	52	49	57	53	56	54	57
AVE	46	50	45	48	46	51	45	48	46	50	47	48	46	48

Table 1, cont'd.

	COOK PLANT										BH		SJ	
Offshore	300 Ft.				2500 Ft.						3375 Ft.		1490 Ft.	
Depth	2 Ft.		4 Ft.		2 Ft.		12 Ft.		17 Ft.		40 Ft.		19 Ft.	
					JUNE 1972									
DATE	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
1	51	56	50	56	56	60	50	53	50	54			51	54
2	55	61	52	58	54	60	52	58	55	58	54	55	51	54
3							55	59	58	66	53	57	57	61
4					53	62	53	59	53	61	57	59	57	61
5					51	60	50	55	51	60	55	58	55	57
6					55	59	51	60	54	60	57	58	53	59
7					51	59	49	51	50	59	51	56	50	53
8					51	58	50	58	52	58	51	58	52	59
9					56	59	55	59	55	59	54	61	58	62
10					44	57	45	57	47	57	51	60	47	61
11					45	56	44	54	44	56	48	52	45	54
12					55	60	54	60	55	60	51	56	54	56
13					58	64	57	60	58	64	56	58	56	61
14					59	66	59	64	59	66	57	61	60	63
15					61	67	60	64	62	67	61	63	61	64
16	OUT OF ORDER				52	64	50	57	58	64	58	63	55	64
17					48	55	44	53	46	58	54	58	52	56
18					44	53	44	47	48	54	50	52	50	54
19					45	58	44	49	47	57	50	53	50	53
20					56	65	51	57	51	57	57	57	52	62
21					44	58	43	55	43	55	54	58	48	60
22					43	47	42	47	42	47	49	53	48	55
23					46	49	47	49	47	49	48	51	47	50
24					47	48	47	48	47	48	47	50	48	49
25					47	48	47	48	47	48	49	49	48	48
26					48	54	48	53	48	54	49	51	49	52
27					53	55	53	55	53	55	51	54	52	54
28					55	55	54	55	54	55	54	57	54	56
29					55	68	54	61	54	61	56	57	54	57
30					55	60	54	60	54	56	55	56	54	56
MIN	51	56	50	56	43	47	42	47	42	47	47	49	45	48
MAX	55	61	52	58	61	68	60	64	62	67	61	63	61	64
AVE*	53	59	51	57	51	58	50	56	51	57	53	56	52	57

Table 1, cont'd.

	COOK PLANT										BH		SJ	
Offshore	300 Ft.				2500 Ft.						3375 Ft.		1490 Ft.	
Depth	2 Ft.		4 Ft.		2 Ft.		12 Ft.		17 Ft.		40 Ft.		19 Ft.	
JULY 1972														
DATE	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
1					55	60	53	56	53	56	56	56	56	61
2					52	59	52	59	52	59	55	58	54	60
3					51	53	49	53	49	53	51	54	49	54
4					52	53	50	53	50	53	50	53	49	53
5					51	54	50	52	50	52	52	54	53	54
6					52	57	51	56	51	56	55	58	53	54
7					54	56	51	56	51	56	56	58	54	58
8					57	57	57	59	57	59	58	59	58	59
9					57	59	57	60	58	60	59	61	59	61
10					58	60	61	61	59	61	61	62	61	61
11					59	62	59	62	59	62	61	66	61	63
12					61	65	61	65	61	65	66	67	63	68
13					63	66	64	67	64	67	64	68	68	68
14					65	67	65	67	65	67	68	69	68	70
15					65	69	66	74	65	74	69	70	70	70
16	OUT OF ORDER				64	68	64	70	65	70	69	70	68	70
17					64	68	64	70	65	70	70	71	68	71
18					67	72	66	70	67	72	60	72	69	71
19					58	67	59	70			57	58	68	69
20											59	73	68	73
21											59	73	72	75
22					OUT OF ORDER						58	73	74	76
23											67	74	76	78
24					70	73	70	73			52	57	75	77
25					52	70	52	70			49	52	52	56
26					46	48	47	59			49	53	48	52
27					44	46	44	50			46	49	45	48
28					43	45	43	45			46	46	44	46
29					43	48	43	48			45	45	43	47
30					48	50	48	50			45	48	47	50
31					50	51	49	52			48	49	50	53
MIN					43	45	43	45	49	52	45	45	43	46
MAX*					70	73	70	74	67	74	70	74	76	78
AVE					56	59	55	60	58	62	57	61	60	62

Table 1, cont'd.

	COOK PLANT										BH		SJ	
Offshore	300 Ft.				2500 Ft.						3375 Ft.		1490 Ft.	
Depth	2 Ft.		4 Ft.		2 Ft.		12 Ft.		17 Ft.		40 Ft.		19 Ft.	
					AUGUST 1972									
DATE	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
1					50	58	51	59			49	54	52	60
2					58	63	60	67			52	62	60	65
3					48	64	48	64			54	66	50	65
4					44	48	44	48			47	51	46	50
5					46	49	46	48			47	49	45	49
6					47	52	47	52			48	53	49	53
7					51	58	51	60			51	55	51	56
8					54	58	54	62			48	58	49	58
9					57	58	57	58			58	60	58	60
10					57	58	57	58			60	61	60	63
11					58	59	58	61			61	62	60	61
12					58	61	58	59			62	63	61	62
13					59	59	59	61			62	63	60	62
14					59	59	59	63			63	64	62	66
15					53	63	59	63	OUT		61	63	61	64
16	OUT OF ORDER				59	61	59	63	OF		61	64	61	64
17					61	63	62	66	ORDER		63	65	64	66
18					63	66	64	64			66	67	66	69
19					64	66	65	74			66	67	67	69
20					63	65	63	67			65	68	66	68
21					64	66	64	67			66	71	67	71
22					67	73	69	70			68	71	71	72
23					67	73	68	69			66	72	72	72
24					67	69	66	72			69	72	71	72
25					67	68	67	68			70	71	70	71
26					68	71	67	71			71	71	71	71
27					66	68	67	69			70	73	70	71
28					66	67	67	67			70	71	70	71
29					66	67	68	68			70	71	71	71
30					66	66	66	66			70	71	71	72
31					66	67	66	67			68	72	71	72
MIN					44	48	44	48			47	49	45	49
MAX					68	73	69	74			71	73	72	72
AVE*					59	63	60	64			61	65	62	65

Table 1, cont'd.

	COOK PLANT										BH		SJ	
Offshore	300 Ft.				2500 Ft.						3375 Ft.		1490 Ft.	
Depth	2 Ft.		4 Ft.		2 Ft.		12 Ft.		17 Ft.		40 Ft.		19 Ft.	
SEPTEMBER 1972														
DATE	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
1					65	67	65	67			69	72	69	72
2					55	66	53	65			52	69	53	71
3					51	55	50	54			50	53	52	53
4					51	55	50	55			50	54	51	52
5					55	59	55	59			54	66	52	63
6					58	61	59	61			65	66	65	67
7					61	66	61	67			65	66	67	67
8					62	65	62	66			66	67	67	67
9					52	66	58	62			57	67	57	67
10					56	59	55	59			57	62	56	60
11					56	60	56	63			54	63	54	60
12					56	60	56	61			54	60	53	57
13					59	59	57	62			53	62	53	62
14					54	60	52	61			54	64	55	63
15					53	57	54	58	OUT		55	63	55	63
16	OUT OF ORDER				57	60	58	61	OF		62	64	63	64
17					60	61	60	62	ORDER		62	64	64	65
18					61	66	61	66			64	66	65	66
19					OUT OF ORDER						62	64	62	65
20					59	60	59	60			62	63	59	62
21					55	60	54	60			57	62	59	63
22					50	55	49	54			52	63	55	63
23					49	50	49	50			52	52	50	52
24					49	50	49	50			51	58	50	53
25					49	53	49	57			54	60	51	60
26					53	55	54	56			60	63	60	63
27					50	55	50	55			51	62	54	62
28					50	53	49	59			51	57	52	55
29					52	55	50	59			57	61	56	61
30					51	54	52	54			58	60	60	61
MIN					49	50	49	50			50	52	50	52
MAX*					65	67	65	67			69	72	69	72
AVE					55	59	55	59			57	62	57	62

Table 1, cont'd.

	COOK PLANT										BH		SJ	
Offshore	300 Ft.				2500 Ft.						3375 Ft.		1490 Ft.	
Depth	2 Ft.		4 Ft.		2 Ft.		12 Ft.		17 Ft.		40 Ft.		19 Ft.	
	OCTOBER 1972													
DATE	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
1											58	60	57	58
2											57	58	56	57
3											57	58	56	57
4											57	58	57	57
5											58	58	57	57
6											57	58	57	58
7											58	59	58	58
8											58	59	57	57
9											58	58	56	57
10											57	58	56	56
11											57	57	56	56
12											57	57	56	56
13											57	57	55	56
14											57	57	55	55
15											56	57	55	55
16	SYSTEM REMOVED FOR INSPECTION AND REPAIR										56	56	54	55
17											55	56	53	54
18											54	55	52	53
19											52	54	51	52
20											53	53	52	52
21											53	53	51	52
22											53	54	51	52
23											53	54	52	53
24											53	54	52	52
25											53	54	51	52
26											52	53	51	52
27											53	53	51	52
28											53	53	51	52
29											53	53	51	51
30											52	53	50	51
31											52	52	50	50
MIN											52	52	50	50
MAX											58	60	58	58
AVE*											55	56	54	54

Table 1, cont'd.

	COOK PLANT										BH		SJ	
Offshore	300 Ft.				2500 Ft.						3375 Ft.		1490 Ft.	
Depth	2 Ft.		4 Ft.		2 Ft.		12 Ft.		17 Ft.		40 Ft.		19 Ft.	
	NOVEMBER 1972													
DATE	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
1											52	52	50	50
2											52	52	50	51
3											51	52	50	50
4											51	51	50	50
5											51	52	49	50
6											50	51	48	49
7											51	51	49	49
8											51	51	49	50
9											50	51	49	50
10											50	51	48	49
11											50	51	48	49
12											50	51	48	48
13											50	50	47	48
14											49	51	45	47
15											47	49	45	46
16				NOT IN OPERATION							47	47	45	46
17											47	48	44	46
18											46	47	44	45
19											45	46	43	44
20											45	46	41	43
21											45	46	44	44
22											43	46	43	44
23											43	44	41	43
24											41	43	41	42
25											41	43	41	42
26											42	43	42	43
27											41	43	40	40
28											40	42	39	40
29											40	42	38	39
30											40	41	39	40
MIN											40	41	38	39
MAX											52	52	50	51
AVE*											47	48	45	46

Table 1, cont'd.

	COOK PLANT										BH		SJ	
Offshore	300 Ft.				2500 Ft.						3375 Ft.		1490 Ft.	
Depth	2 Ft.		4 Ft.		2 Ft.		12 Ft.		17 Ft.		40 Ft.		19 Ft.	
	DECEMBER 1972													
DATE	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
1											39	41	37	38
2											39	40	38	39
3											40	41	39	39
4											40	40	38	39
5											40	40	38	39
6											39	39	35	39
7											38	39	36	37
8											38	40	33	37
9											39	40	36	36
10											38	39	35	37
11											36	39	34	35
12											36	37	34	34
13											36	37	34	34
14											35	36	34	34
15											35	36	34	34
16					NOT IN OPERATION						35	36	32	33
17											35	35	33	33
18											34	35	32	32
19											34	35	32	32
20											34	34	32	33
21											34	35	33	33
22											35	35	33	33
23											34	35	33	33
24											34	36	33	33
25											35	37	33	33
26											35	35	33	33
27											35	35	33	33
28											35	36	33	34
29											35	36	33	34
30											35	37	34	34
31											36	37	35	35
MIN											34	34	32	32
MAX											40	41	39	39
AVE*											36	37	34	35

Table 1, cont'd.

	COOK PLANT										BH		SJ	
Offshore	300 Ft.				2500 Ft.						3375 Ft.		1490 Ft.	
Depth	2 Ft.		4 Ft.		2 Ft.		12 Ft.		17 Ft.		40 Ft.		19 Ft.	
					JANUARY 1973									
DATE	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
1											36	37	33	34.5
2											35	36	32.5	33.5
3											35	35	32.5	33
4											34	35	33	33.5
5											34	34	32	32.5
6											34	34	32	32.5
7											34	34	32	32.5
8											34	34	32	32.5
9											34	34	32	32.5
10											34	34	32	32
11											34	34	32	32.5
12											34	34	32	32.5
13											34	34	32	32.5
14											34	34	32	32.5
15											34	34	32	32.5
16					NOT IN OPERATION						34	34	32	32
17											34	34	32	32
18											34	35	32	33
19											35	36	32.5	33.5
20											35	35	32.5	34
21											35	35	33	35.5
22											35	35	33.5	34
23											35	36	33	34
24											35	36	33	33.5
25											36	36	33	33.5
26											36	36	33	34
27											36	37	33.5	34.5
28											36	37	33.5	35
29											35	36	32.5	33.5
30											35	36	32	32.5
31											35	35	32	34
MIN											34	34	32	32
MAX											36	37	33.5	35.5
AVE*											35	35	33	33

Table 2. Frequencies and magnitudes of natural daily temperature changes at Benton Harbor and St. Joseph water filtration plants in 1970 through 1972.

Daily Change °F	JAN			FEB			MAR			APR			MAY			JUN		
	70	71	72	70	71	72	70	71	72	70	71	72	70	71	72	70	71	72
3 - 5	ND	-	-	ND	1	-	ND	2	5	ND	11	15	13	10	16	19	26	30
6 - 8	ND	-	-	ND	1	-	ND	-	-	ND	-	-	1	2	2	6	9	5
9 - 11	ND	-	-	ND	-	-	ND	-	-	ND	-	-	-	-	-	6	2	4
12 - 14	ND	-	-	ND	-	-	ND	-	-	ND	-	-	-	-	-	3	1	2
15 - 17	ND	-	-	ND	-	-	ND	-	-	ND	-	-	-	-	-	2	-	-
18 - 20	ND	-	-	ND	-	-	ND	-	-	ND	-	-	-	-	-	2	1	-
21 - 23	ND	-	-	ND	-	-	ND	-	-	ND	-	-	-	-	-	-	-	-
24 - 26	ND	-	-	ND	-	-	ND	-	-	ND	-	-	-	-	-	-	-	-
27 - 29	ND	-	-	ND	-	-	ND	-	-	ND	-	-	-	-	-	-	-	-
2-Plant Monthly Fraction	ND	0/62	0/62	ND	2/56	0/56	ND	2/62	5/62	ND	11/60	15/60	14/42	12/58	18/62	38/60	39/60	41/59

Daily Change °F	JUL			AUG			SEP			OCT			NOV			DEC		
	70	71	72	70	71	72	70	71	72	70	71	72	70	71	72	70	71	72
3 - 5	17	17	26	16	17	21	ND	5	17	3	5	-	2	2	1	-	-	2
6 - 8	2	11	2	16	7	2	ND	7	10	1	2	-	-	-	-	-	-	-
9 - 11	1	6	-	11	9	3	ND	4	10	-	-	-	-	-	-	-	-	-
12 - 14	-	1	3	1	4	1	ND	4	1	-	-	-	-	-	-	-	-	-
15 - 17	1	5	1	2	1	1	ND	-	1	-	-	-	-	-	-	-	-	-
18 - 20	2	1	-	2	2	-	ND	-	1	-	-	-	-	-	-	-	-	-
21 - 23	-	-	-	-	1	-	ND	-	-	-	-	-	-	-	-	-	-	-
24 - 26	1	-	-	-	-	-	ND	-	-	-	-	-	-	-	-	-	-	-
27 - 29	-	-	-	-	-	-	ND	-	-	-	-	-	-	-	-	-	-	-
2-Plant Monthly Fraction	24/62	41/61	32/62	48/62	41/62	27/62	ND	20/60	40/60	4/62	7/62	0/62	2/60	2/60	1/60	0/62	0/62	2/62

ND = No data.
\- = This magnitude of temperature variation was not reached.

Table 3. Frequencies and magnitudes of natural daily temperature changes at the 2 foot and 12 foot thermistors at the 2,500 foot position off the Cook Plant in 1970 through 1972.

Daily Change °F	JAN			FEB			MAR			APR			MAY			JUN		
	70	71	72	70	71	72	70	71	72	70	71	72	70	71	72	70	71	72
3 - 5	ND	-	ND	ND	2	ND	ND	2	ND	ND	-	ND	16	4	20	18	9	19
6 - 8	ND	-	ND	ND	-	ND	ND	-	ND	ND	-	ND	2	3	2	10	-	16
9 - 11	ND	-	ND	ND	-	ND	ND	-	ND	ND	-	ND	-	-	-	4	1	8
12 - 14	ND	-	ND	ND	-	ND	ND	-	ND	ND	-	ND	-	-	1	3	2	7
15 - 17	ND	-	ND	ND	-	ND	ND	-	ND	ND	-	ND	-	-	1	1	-	-
18 - 20	ND	-	ND	ND	-	ND	ND	-	ND	ND	-	ND	-	-	-	2	-	-
21 - 23	ND	-	ND	ND	-	ND	ND	-	ND	ND	-	ND	-	-	-	-	-	-
24 - 26	ND	-	ND	ND	-	ND	ND	-	ND	ND	-	ND	-	-	-	-	-	-
27 - 29	ND	-	ND	ND	-	ND	ND	-	ND	ND	-	ND	-	-	-	-	-	-
2-Depth Monthly Fraction	ND	0/62	ND	ND	2/56	ND	ND	2/62	ND	ND	0/62	ND	18/42	7/58	24/32	38/60	12/60	50/59

Daily Change °F	JUL			AUG			SEP			OCT			NOV			DEC		
	70	71	72	70	71	72	70	71	72	70	71	72	70	71	72	70	71	72
3 - 5	17	4	25	11	ND	18	9	ND	32	14	ND	ND	3	ND	ND	3	ND	ND
6 - 8	2	6	8	8	ND	8	5	ND	5	1	ND	ND	-	ND	ND	-	ND	ND
9 - 11	-	3	2	8	ND	3	-	ND	4	2	ND	ND	-	ND	ND	-	ND	ND
12 - 14	-	1	1	4	ND	-	1	ND	2	-	ND	ND	-	ND	ND	-	ND	ND
15 - 17	-	1	-	-	ND	2	7	ND	-	-	ND	ND	-	ND	ND	1	ND	ND
18 - 20	1	-	-	-	ND	-	2	ND	-	-	ND	ND	-	ND	ND	-	ND	ND
21 - 23	-	-	-	-	ND	-	-	ND	-	-	ND	ND	-	ND	ND	-	ND	ND
24 - 26	2	-	-	-	ND	-	-	ND	-	-	ND	ND	-	ND	ND	-	ND	ND
27 - 29	1	-	-	-	ND	-	-	ND	-	-	ND	ND	-	ND	ND	-	ND	ND
2-Depth Monthly Fraction	23/62	15/54	36/54	31/46	ND	31/62	24/50	ND	43/58	17/64*	ND	ND	3/50	ND	ND	4/52	ND	ND

ND = No data.
\- = This magnitude of temperature variation was not reached.
*2 sets of data on one day.

Table 4. Percent of days that natural variations of $3^{o}F$ or more occurred. (From the monthly fractions of Tables 2 and 3.)

Month & Year	BH - SJ	COOK PLANT
Jan 1970	no data	no data
1971	0.0	0.0
1972	0.0	no data
Feb 1970	no data	no data
1971	3.6	3.6
1972	0.0	no data
Mar 1970	no data	no data
1971	3.2	3.2
1972	8.1	no data
Apr 1970	no data	no data
1971	18.3	0.0
1972	25.0	no data
May 1970	33.3	42.8
1971	20.7	12.1
1972	29.0	75.0
Jun 1970	63.3	63.3
1971	65.0	20.0
1972	69.5	84.7
Jul 1970	38.7	37.1
1971	67.2	27.8
1972	51.6	66.7
Aug 1970	77.4	67.4
1971	66.1	no data
1972	43.5	50.0
Sep 1970	no data	48.0
1971	33.3	no data
1972	66.6	74.1
Oct 1970	6.4	26.6
1971	11.3	no data
1972	0.0	no data
Nov 1970	3.3	6.0
1971	3.3	no data
1972	1.7	no data
Dec 1970	0.0	7.7
1971	0.0	no data
1972	3.2	no data

Tables 2, 3, and 4 depict the frequencies and magnitudes of preoperational water temperature variations to which the benthos, periphyton, macrophyton, and psammon are naturally exposed and presumably acclimated, for they exist in the region.

A.2 *Study of Floating Algae and Bacteria*

This portion of the report is in two sections. The first is a discussion of the monthly phytoplankton collections at the Cook Plant in 1972, and the second is a report on Biomasses, numbers, and cell weights of Lake Michigan phytoplankton, by John C. Ayers and Erwin Seibel, prepared in January 1973 as an interim report. This interim report is included here in its entirety.

Section 1. Monthly phytoplankton collections at the Cook Plant in 1972

John C. Ayers and Erwin Seibel

Seasonal surveys of phytoplankton in the Cook Plant area were carried out in April (54 station grid of sampling stations), July (36 station grid), and October (36 station grid). The data from these are not yet available and will be reported later. The seasonal surveys are aimed at the determination of any species composition changes over the long term. The monthly surveys presented here are concerned with temporal variations observed in 1972 under natural preoperational conditions.

From April through November 1972, monthly phytoplankton collections were carried out on a seven to nine station grid of sampling stations in front of the Cook Plant. At station DC-0 in the surf zone, collections were made by immersing a liter capacity brown polyethylene bottle below the surface; at all other stations collections were made with a Niskin bottle from a depth of one meter. Preservation was by Utermohl's iodine solution.

In April through June, counts and identifications were made by the Utermohl settling chamber and inverted microscope method; from July through November counts and identifications were made by the settle-freeze method of Sanford, Sands and Goldman, 1969[1]. Reasons for the change of method are given below.

The layout of sampling stations is shown in Figure 1. Station DC-1 was unoccupiable from August through November because dredges were working at the station position during these months. Station DC-0 was not a part of the major surveys in April, July, and October. Stations NDC-.5-1 and SDC-.5-1 were not included in the 36-station major surveys in July and October, but were included in the 54-station survey of April; for July and October the data of stations NDC-.5-2 and SDC-.5-2 (a half mile off shore instead of a quarter mile) were substituted. In these shallow inshore waters any error in phytoplankton results due to the quarter mile greater distance from shore is believed to be minimal.

This study was conducted primarily to ascertain whether spring, summer, and fall seasonal samplings could adequately represent the temporal sequence of phytoplankton numbers, and to determine the best available representative months for the seasonal samplings.

Emphasis has been placed upon phytoplankton numbers because we were convinced of the necessity to change techniques from the Utermohl chamber method to the settle-freeze method. Our experience with the Utermohl method had revealed that detritus, clumping, and the optics of its wet samples were interfering with desirable identification of species. The settle-freeze method gives permanent mounts, better species identification, and more accurate

1. Sanford, G. R., A. Sands, and C. R. Goldman. 1969. A settle-freeze method for concentrating phytoplankton in quantitative studies. Limn. and Oceanog., 14(5):790-794.

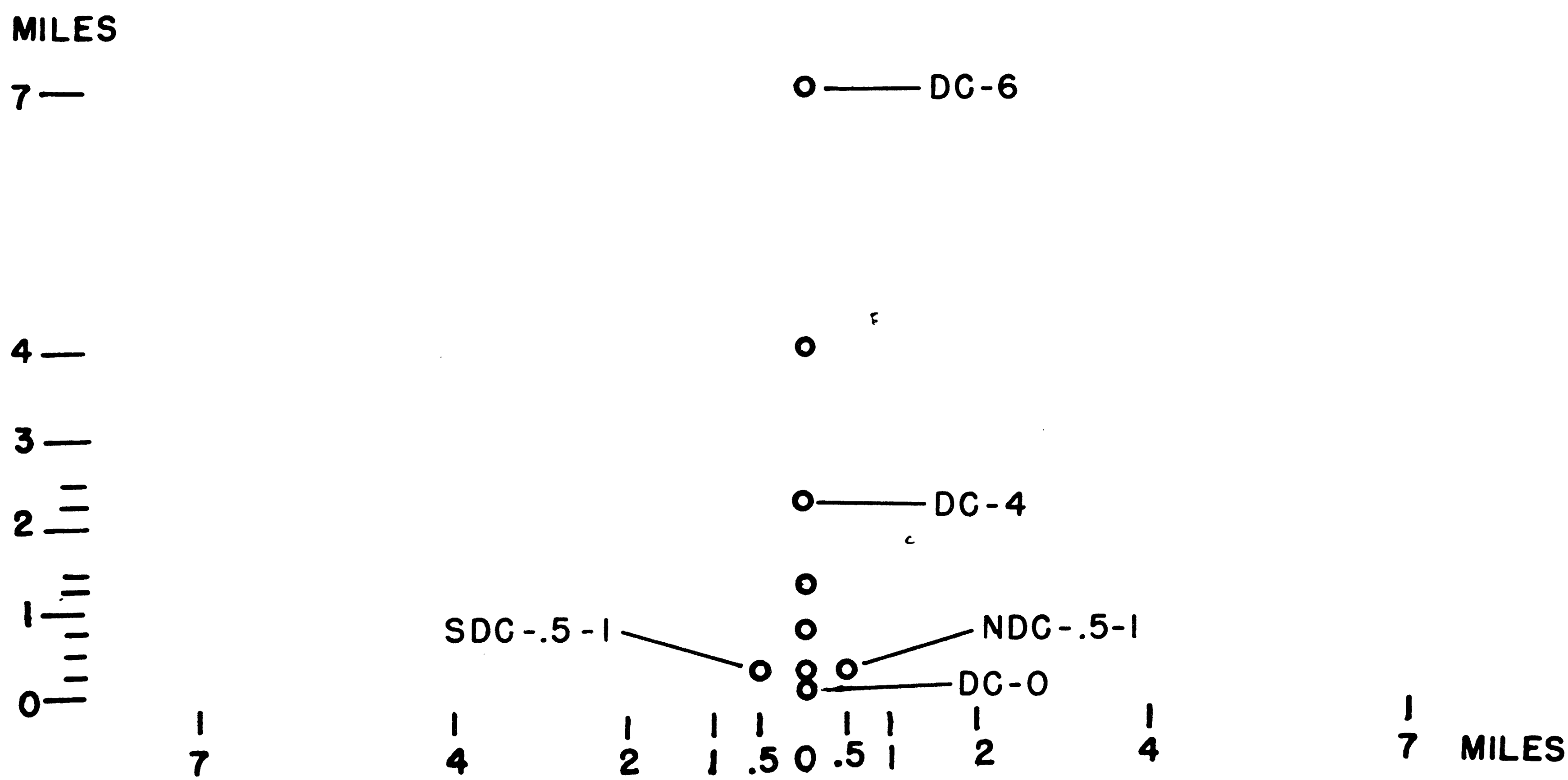

Figure 1. The minimal Cook Plant survey grid. Used in months between season surveys.

counts. The least difference between the methods was in counts per ml.

We thus have April, May, and June by the Utermohl method in which to look for a representative spring sampling month, and July through November by the settle-freeze method in which to seek the most representative summer and fall sampling months.

Although we had reasonable faith that cell numbers obtained by the two methods were comparable, we knew that the better species identification by the settle-freeze method was giving reduction in numbers of cells in certain grouped categories by splitting into species various forms which weaknesses of the Utermohl method had lumped into the "spp." categories.

In order to test this, as well as to test the reality of low cell counts obtained in July, we have, with the advice of Dr. E. F. Stoermer, recombined (relumped) identified species of supposedly comparable ecological valence back into the grouped "spp." category. Table 5 presents these tests on the genera *Ankistrodesmus*, *Melosira*, and *Stephanodiscus* (in the latter only the small and difficult forms *S. binderanus*, *S. hantzschii*, *S. minutus*, *S. subtilis*, and *S. tenuis* were recombined with the unidentified "spp." forms).

In *Ankistrodesmus* and *Melosira* the recombining produced smoother transitions across the July low counts, but did not eliminate the July lows. In *Stephanodiscus* there still remained an abrupt change in numbers from June to July. At present we believe that the July low counts should be considered real until the settle-freeze method can be extended through July 1973.

During the eight months of collections 164 species or groups of phytoplankters were taken. For presentation we have arbitrarily separated them into "Abundant" and "Rare" at 100 cells collected during the eight months. The counts of the 32 species or groups in the "Abundant" category are presented by stations and months in Table 6.

Table 5. Test recombinations of identified and unidentified forms of the genera *Ankistrodesmus*, *Melosira*, and *Stephanodiscus*. See text for explanation. Dashes indicate that the station was not occupied in that month.

Ankistrodesmus spp. (recombined)

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	18	12	-	7	12	8	9	6	4
May	21	23	6	10	7	8	12	4	11
Jun	0	10	7	11	6	6	9	21	12
Jul	0	2	-	1	5	1	0	2	2
Aug	0	4	0	-	4	0	2	4	2
Sep	1	2	0	-	1	1	1	2	1
Oct	2	0	-	-	2	1	0	0	0
Nov	1	1	0	-	0	1	1	0	1

Melosira spp. (recombined)

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	15	28	-	35	46	45	19	28	0
May	16	13	1	6	6	7	7	13	51
Jun	11	11	37	18	12	6	11	3	7
Jul	1	0	-	0.5	0	0	0	0	0
Aug	4	4	6	-	2	0.5	2	0	0
Sep	5	35	28	-	4	6	0	0	0
Oct	870	527	-	-	978	370	440	77	8
Nov	162	82	50	-	73	126	34	13	6

Stephanodiscus spp. (recombined)

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	213	26	-	30	28	32	22	54	5
May	17	94	44	53	75	64	71	38	1
Jun	378	328	1,035	425	111	85	108	67	69
Jul	2	5	-	9	3	0	1	0	0
Aug	6	12	23	-	15	14	8	2	0
Sep	1	2	4	-	0	1	1	1	0
Oct	20	16	-	-	23	18	11	9	1
Nov	32	14	21	-	12	23	5	8	13

Table 6. The 32 abundant phytoplankton forms in the 1972 collections at the Cook Plant, by stations and months. Dashes indicate that the station was not occupied in that month.

Anabaena spp. (colonies)

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	0	0	-	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0
Jun	4	0	0	0	0	0	0	0	0
Jul	12	11	-	5	21	6	3	1	1
Aug	2	1	0	-	3	6	4	3	6
Sep	1	0.5	1	-	2	0.5	0.5	0.5	0
Oct	1	0	-	-	0	0	2	2	2
Nov	0	0.5	0	-	0	0	0.5	1	2

Ankistrodesmus spp.

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	18	12	-	7	6	0	3	4	0.5
May	21	23	6	10	7	8	12	4	6
Jun	0	10	7	11	6	6	9	21	12
Jul	0	2	-	1	0	0	0	0	0
Aug	0	0	0	-	0	0	0	0	0
Sep	0	0	0	-	0	0	0	0	0
Oct	0	0	-	-	0	0	0	0	0
Nov	0	0	0	-	0	0	0	0	0

Asterionella formosa

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	23	0	-	2	0	1	2	2	0
May	77	135	77	93	73	91	56	16	0
Jun	22	7	0	6	14	13	16	45	47
Jul	1	0	-	0	0	1	0	2	5
Aug	4	2	7	-	6	7	4	32	8
Sep	4	28	34	-	13	3	0	0	9
Oct	44	25	-	-	84	44	43	15	9
Nov	155	93	180	-	48	82	28	11	8

Table 6, cont'd.

Chlamydomonas spp.

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	52	83	-	72	116	178	163	116	57
May	14	16	2	6	25	54	27	9	38
Jun	85	9	15	6	6	115	9	4	13
Jul	0	19	-	2	1	0	0.5	3	0
Aug	0	0	0	-	1	0	0	0	0.5
Sep	0	0	0	-	0	0	0	0	0
Oct	6	0	-	-	0	1	0	0	3
Nov	0	0	0	-	0	0	0	0	0

Chroococcus spp. (mostly *limneticus*)

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	0	0	-	0	0	0.5	0	0	0
May	0	0	0	0	0	0	0	0	0.5
Jun	0	0	0	0	0	0	0	0	2
Jul	0	0	-	0	0	0	0	0	0
Aug	0	0	4	-	1	0	0	0	2
Sep	83	106	52	-	137	142	240	279	288
Oct	100	38	-	-	128	117	166	219	462
Nov	58	60	33	-	41	86	95	47	119

Cryptomonas spp.

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	12	49	-	44	28	21	21	19	7
May	9	14	2	14	3	4	6	3	9
Jun	0	11	59	6	6	0	6	8	2
Jul	1	2	-	0	2	1	2	0	1
Aug	1	1	0	-	5	6	4	15	12
Sep	7	13	4	-	9	12	3	10	8
Oct	38	17	-	-	26	16	10	12	25
Nov	5	2	2	-	3	7	4	0	1

Table 6, cont'd.

Cyclotella kutzinginiana

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	0	0	-	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0
Jun	0	0	0	0	0	0	0	0	0
Jul	0	0	-	0	0	0	0	0	0.5
Aug	0	1	0	-	1	2	2	4	0
Sep	0	0	0	-	0	0.5	0	0	0
Oct	3	6	-	-	5	5	7	3	3
Nov	18	7	9	-	7	10	6	2	2

Cyclotella stelligera

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	1	0	-	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0
Jun	0	0	0	0	0	0	0	0	0
Jul	4	0	-	0	5	4	2	20	45
Aug	5	7	0	-	0	0	0	1	0
Sep	0	0	0	-	0	0	0	0	0
Oct	2	3	-	-	0	3	1	0	1
Nov	10	5	0	-	2	6	3	5	3

Cyclotella spp.

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	237	0	-	0	0	2	3	6	0
May	98	135	96	48	66	100	73	64	0
Jun	40	429	1,710	323	174	4	159	146	224
Jul	1	0	-	0	1	0.5	4	1	2
Aug	1	1	15	-	9	6	8	4	9
Sep	0.5	0.5	1	-	0	0.5	0.5	0	0
Oct	0	1	-	-	0	1	0	1	0
Nov	4	4	2	-	4	5	1	2	0.5

Table 6, cont'd.

Diatoma tenue v. elongatum

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	0	23	-	49	18	16	22	8	0
May	0	0	0	0	0	0	0	0	1
Jun	0	0	0	2	3	0	9	19	13
Jul	0	0	-	0	0.5	0	0	0	0
Aug	0.5	0	0	-	0	0	0	0	0
Sep	0	0	0	-	0	0	0	0	0
Oct	2	0	-	-	2	0	1	0.5	0
Nov	0	0	0	-	0	1	0	0	0

Dinobryon divergens

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	6	23	-	19	13	12	5	3	0
May	5	13	6	5	18	16	14	38	5
Jun	0	8	11	14	22	2	35	63	17
Jul	7	20	-	24	4	1	0	3	5
Aug	1	1	10	-	0	0	0	0.5	0
Sep	2	15	0	-	14	12	12	8	5
Oct	0	0	-	-	0	0	2	0	0
Nov	0	0	0	-	0.5	0.5	0	0	0

Dinoflagellates

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	0	0	-	0	0	1	0	0	0
May	0	0	0	0	0	0	0	0	2
Jun	0	0	0	0	0	0	0	0	0
Jul	1	0	-	0	4	1	0	4	3
Aug	0	2	7	-	1	1	0	0	1
Sep	0.5	1	0	-	0	1	0	0.5	1
Oct	1	6	-	-	2	0	27	6	2
Nov	31	11	17	-	9	24	16	1	10

Table 6, cont'd.

Flagellates

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	122	223	-	132	68	25	14	37	27
May	240	396	43	229	225	440	297	290	196
Jun	0	104	93	58	51	0	108	95	91
Jul	15	0	-	5	39	30	6	67	44
Aug	12	14	6	-	28	26	39	73	109
Sep	13	19	3	-	15	18	15	51	11
Oct	244	210	-	-	267	224	172	69	143
Nov	245	152	32	-	31	187	144	52	164

Fragilaria capucina

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	1	0	-	0	0	3	0	2	0
May	8	87	36	40	41	23	24	0	0
Jun	193	0	523	48	36	0	93	96	40
Jul	19	3	-	22	28	0	0	0	0
Aug	0	0	4	-	2	0	0	0	0
Sep	20	0	0	-	0	0	0	0	0
Oct	0	0	-	-	61	0	0	0	0
Nov	18	3	0	-	0	28	0	0	0

Fragilaria crotonensis

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	18	30	-	9	21	23	12	11	0
May	36	74	41	101	43	65	49	39	2
Jun	0	107	104	6	17	32	16	6	6
Jul	0	12	-	9	15	0	11	12	55
Aug	275	160	234	-	221	111	194	333	249
Sep	15	41	72	-	27	13	6	13	1
Oct	299	144	-	-	276	89	211	14	16
Nov	306	96	1,185	-	134	446	49	47	52

Table 6, cont'd.

Fragilaria intermedia

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	0.5	7	-	2	28	16	10	24	0
May	59	105	31	113	5	13	0	9	1
Jun	0	24	612	114	19	46	12	2	76
Jul	0	2	-	37	1	0	0	0	0
Aug	0	1	13	-	0	0	0	0	0
Sep	0	0	0	-	0	0	0	0	0
Oct	12	10	-	-	0	6	0	0	0
Nov	18	10	63	-	0	10	0	0	0

Glenodinium spp.

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	14	28	-	16	19	15	21	13	0.5
May	1	3	0	3	6	8	3	13	0
Jun	0	4	0	6	1	0	3	6	5
Jul	9	15	-	9	7	9	4	4	0
Aug	3	1	4	-	3	1	1	2	0.5
Sep	0	0.5	3	-	1	1	1	1	0
Oct	0	0	-	-	2	0	0	0	0
Nov	0	0	0	-	0	0	0	0	0

Gloeocystis spp.

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	105	118	-	132	133	116	58	56	14
May	70	233	42	89	18	81	29	41	27
Jun	0	8	119	1	4	19	19	43	16
Jul	21	1	-	0	47	48	6	59	11
Aug	18	44	35	-	52	88	53	89	200
Sep	28	55	10	-	33	66	60	75	99
Oct	63	88	-	-	46	71	18	15	37
Nov	51	17	315	-	77	42	31	2	16

Table 6, cont'd.

Melosira granulata

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	0	0	-	0	1	0	0	0	0
May	0	0	0	0	0	0	0	0	0
Jun	0	0	0	0	0	0	0	0	0
Jul	1	0	-	0	0	0	0	0	0
Aug	4	4	6	-	2	0.5	2	0	0
Sep	3	34	27	-	4	6	0	0	0
Oct	858	524	-	-	866	355	439	74	6
Nov	162	82	50	-	73	126	34	13	6

Melosira granulata v. angustissima

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	0	0	-	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0
Jun	0	0	0	0	0	0	0	0	0
Jul	0	0	-	0	0	0	0	0	0
Aug	0	0	0	-	0	0	0	0	0
Sep	0	1	0	-	0	0	0	0	0
Oct	10	3	-	-	110	12	0	2	0
Nov	0	0	0	-	0	0	0	0	0

Melosira islandica

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	9	0	-	7	34	34	17	24	0
May	0	1	0	0	1	0	0	0	51
Jun	0	0	0	0	0	0	0	0	0
Jul	0	0	-	0	0	0	0	0	0
Aug	0	0	0	-	0	0	0	0	0
Sep	2	0	1	-	0	0	0	0	0
Oct	0	0	-	-	0	0	0	0	0
Nov	0	0	0	-	0	0	0	0	0

Table 6, cont'd.

Melosira spp.

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	6	28	-	28	11	10	2	4	0
May	4	6	1	3	3	2	1	6	0
Jun	0	6	33	12	11	2	5	3	3
Jul	0	0	-	0.5	0	0	0	0	0
Aug	0	0	0	-	0	0	0	0	0
Sep	0	0	0	-	0	0	0	0	0
Oct	0	0	-	-	0	0	0	0	0
Nov	0	0	0	-	0	0	0	0	0

Nitzschia spp.

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	1	0	-	0	3	0	1	2	0
May	3	0	0	0	0.5	0	0	0	0
Jun	4	1	7	2	0	0	0	0	6
Jul	8	0	-	1	1	0	0	0	0
Aug	0.5	0	2	-	0.5	0.5	0	0	0
Sep	2	4	10	-	0	0	0	0	0
Oct	8	7	-	-	1	3	2	0.5	0
Nov	4	3	0	-	3	3	2	0.5	2

Oocystis spp.

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	0	2	-	2	0.5	1	0.5	0	1
May	0	0	0	0	0	0	0	0	1
Jun	0	5	4	1	0	0	1	1	1
Jul	18	0	-	3	39	9	0	21	1
Aug	10	10	7	-	7	15	15	11	26
Sep	56	89	29	-	61	88	78	152	199
Oct	40	18	-	-	27	19	11	16	41
Nov	18	22	0	-	5	18	12	16	17

Table 6, cont'd.

Rhizosolenia gracilis

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	11	16	-	25	49	40	35	25	2
May	0	0	0	0	0	0	0	0	0
Jun	0	0	0	0	0	0	0	0	0
Jul	0	0	-	0	0	0	0	0	0
Aug	0	0	0	-	0	0	0	0	0
Sep	0	0	0	-	0	0	0	0	0
Oct	0	0	-	-	0	0	0	0	0
Nov	0	0	0	-	0	0	0	0	0

Rhizosolenia sp. (unidentified)

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	4	0	-	0	0	0	0	0	0
May	5	2	0	1	5	8	6	23	33
Jun	0	0	0	3	2	5	0	2	2
Jul	0	0	-	0	0	0	0	0	0
Aug	0	0	0	-	0	0	0	0	0
Sep	0	0	0	-	0	0	0	0	0
Oct	0	0	-	-	0	0	0	0	0
Nov	0	0	0	-	0	0	0	0	0

Scenedesmus quadricauda

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	0	0	-	0	0.5	0	0.5	0	0
May	0	0	0	0	0	0	0	0	0
Jun	0	1	4	0	0	0	1	0	0
Jul	6	0	-	0	6	4	0	0	917
Aug	2	0	0	-	0	0	0	0	0
Sep	0	0	0	-	0	0	0	0	0
Oct	21	0	-	-	8	9	0	0	0
Nov	0	7	0	-	5	0	0	1	0

Table 6, cont'd.

Scenedesmus spp.

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	13	7	-	7	16	20	13	14	1
May	31	26	16	11	10	14	6	9	10
Jun	15	17	48	13	18	6	24	19	30
Jul	0	2	-	1	0	0	0.5	0	0
Aug	0	0	7	-	1	0	4	2	42
Sep	0	6	1	-	1	2	1	0	0
Oct	0	19	-	-	0	2	0	4	0
Nov	2	0	0	-	2	2	2	0	0

Stephanodiscus alpinus

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	0	0	-	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0
Jun	103	0	0	0	0	7	0	0	0
Jul	0	0	-	0	0.5	0	0	0	0
Aug	3	2	0	-	1	2	1	1	0
Sep	0	0	0	-	0	0	0	0	0
Oct	1	1	-	-	5	3	3	0.5	0
Nov	8	1	9	-	2	3	0	1	1

Stephanodiscus spp.

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	213	26	-	30	28	32	22	54	5
May	17	94	44	53	75	64	71	38	1
Jun	378	328	1,035	425	111	85	108	67	69
Jul	2	5	-	9	0	0	0.5	0	0
Aug	0.5	1	17	-	3	3	0.5	1	0
Sep	0.5	2	4	-	0	0.5	0.5	0.5	0
Oct	7	6	-	-	0	0	1	2	0.5
Nov	10	3	4	-	3	10	1	2	2

Table 6, cont'd.

Synedra ulna

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	2	0	-	0	0.5	1	1	0	0
May	4	2	6	8	6	6	4	0.5	0.5
Jun	26	13	45	9	4	9	13	26	5
Jul	0	0	-	0	0	0	0	0	0
Aug	0	0	0	-	0	0	0	0	1
Sep	0	0	0	-	0	0	0	0	0
Oct	3	2	-	-	6	0	1	0	1
Nov	6	0.5	0	-	2	2	2	0	0

Tabellaria fenestrata

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	123	438	-	308	345	399	323	275	10
May	515	662	165	515	373	302	243	45	3
Jun	141	38	197	69	62	93	18	48	9
Jul	35	104	-	27	109	2	20	10	0
Aug	88	47	132	-	16	30	29	75	93
Sep	35	13	67	-	0	3	0	0.5	7
Oct	85	18	-	-	128	11	152	6	8
Nov	482	178	814	-	113	474	178	16	69

Table 7 is the eight months' total list of species and groups; this table also indicates "Abundant," "Rare," and "riverine" by A, R, and r on the left and shows on the right the total monthly collections of the rare forms at all stations. Species and forms are presented in the way in which they are recognized and counted. Examples are: *Glenodinium*, a dinoflagellate, is recognized and counted separately from unidentified dinoflagellates which are given as "Dinoflagellates;" the flagellates *Cryptomonas* and *Chlamydomonas* are recognized and counted separately from unidentified "Flagellates;" *Anacystis* and *Chroococcus* are recognized as separate entities, rather than as species of *Anacystis*.

Table 8 presents by month the dominant species or group in the collections, and the percentage of those organisms in the monthly collections. In no month did the dominant(s) heavily dominate the collections. The greatest dominance was 37% for *Fragilaria crotonensis* in August.

Table 9 gives the total numbers of cells per ml collected, the total numbers of species or groups (forms) recognized, and (for what it is worth as a measure of diversity) the mean numbers of cells per ml per form for each station in each month. This table indicates generally rather high numbers of cells per ml in April, May, and June. Low numbers of cells per ml appear to be typical in July, August, and September. October and November show, again, rather high cell counts.

Of the first three months, April had somewhat larger numbers of forms and lower mean numbers of cells per form than was true for May or June. The lower total cell counts in July, August, and September were not matched by a proportionate decrease in numbers of forms, and generally low mean numbers of cells per form were typical of these months. Increased cell counts in October and November were not accompanied by a proportionate increase in num-

Table 7. Master species list 1972 indicating "Abundant," "Rare," and "riverine" by A, R, and r on the left.

	Species	Total monthly collections of rare forms at all stations
R	*Achnanthes* spp.	Apr 1, Nov 1
R	*Actinastrum hantzschii v. fluviatile*	Apr 2.5
R	*Actinastrum* spp.	Jun 94
R	*Amphipleura pellucida*	Jul 1.5
R	*Amphiprora ornata*	Apr 0.5
R(r)	*Amphora ovalis*	Jun 4, Oct 1
R(r)	*Amphora* spp.	May 1
A	*Anabaena* spp.	
R	*Anacystis* spp.	May 1.5, Nov 39
R	*Ankistrodesmus falcatus*	Apr 0.5, Jul 3, Aug 1, Sep 7.5, Oct 1
R	*Ankistrodesmus falcatus v. mirabilis*	Apr 20, May 4, Aug 0.5
R	*Ankistrodesmus gelifactum*	Apr 4, May 0.5, Aug 1
R	*Ankistrodesmus* sp. #1	Oct 2, Nov 4
R	*Ankistrodesmus* sp. #2	Oct 2
R	*Ankistrodesmus* sp. #3	Jul 3, Aug 1, Oct 2, Nov 0.5
R	*Ankistrodesmus* sp. #5	Jul 3.5, Aug 14
A	*Ankistrodesmus* spp.	
R	*Aphanocapsa* spp.	Jun 1, Oct 2
R	*Aphanothece* spp.	Apr 1.5, May 2
A	*Asterionella formosa*	
R	*Asterococcus limneticus*	Jul 1
R	Blue-green colonies	Apr 1
R	Blue-green filaments	Apr 16.5, May 3, Jun 7, Oct 3, Nov 1.5
R	*Ceratium hirundinella*	Jul 1.5, Aug 1, Sep 22, Oct 3, Nov 0.5
A	*Chlamydomonas* spp.	
A	*Chroococcus* spp. (mostly *limneticus*)	
R	*Closteriopsis longissima*	Apr 4, May 4, Jul 0.5
R	*Closterium aciculare*	Apr 1, May 1
R	*Closterium* spp.	Apr 14.5, May 10
R	*Cocconeis* spp.	Apr 0.5

Table 7 con't.

	Species	Total monthly collections of rare forms at all stations
R	*Coelastrum* spp.	Apr 4.5, May 0.5, Jul 1. Sep 19.5, Oct 0.5
R	*Coelosphaerium collinsii*	Oct 18
R	*Coelosphaerium* spp.	Apr 0.5, Aug 0.5, Oct 1
R	*Cosmarium* spp.	Apr 7, May 6.5, Jun 3, Jul 3.5, Aug 5.5, Sep 2.5, Oct 9.5, Nov 1
R	*Crucigenia quadrata*	Oct 23, Nov 18
R	*Crucigenia* spp.	May 23, Jun 8, Aug 4, Sep 28
A	*Cryptomonas* spp.	
R	*Cyclotella atomus*	Aug 2
R	*Cyclotella comta*	Jul 1, Aug 17, Sep 10.5, Oct 6, Nov 6
R	*Cyclotella cryptica*	Oct 6.5, Nov 2
R	*Cyclotella glomerata*	Jul 1
A	*Cyclotella kutzinginiana*	
R(r)	*Cyclotella meneghiniana*	Aug 8.5, Oct 4, Nov 2
R	*Cyclotella michiganiana*	Jul 12.5, Aug 43.5, Oct 12.5, Nov 10.5
R	*Cyclotella ocellata*	Apr 13, May 18, Jun 34, Jul 0.5, Sep 0.5
A	*Cyclotella stelligera*	
A	*Cyclotella* spp.	
R	*Cymbella* spp.	Nov 0.5
R	*Cymatopleura solea*	Apr 2, May 5.5, Jun 20, Sep 0.5, Oct 0.5, Nov 4
R	*Dactylococcopsis* spp.	Nov 1
A	*Diatoma tenue v. elongatum*	
R	*Diatoma vulgare*	Apr 0.5. Oct 0.5
R	*Diatoma* spp.	May 0.5
R	*Dictyosphaerium* spp.	Apr 1, May 0.5, Jun 42
R	*Dinobryon* cysts	Apr 38, May 20, Jun 6
A	*Dinobryon divergens*	
R	*Dinobryon sociale*	Jul 6.5, Sep 1
A	Dinoflagellates	
R	*Diploneis* sp. #1	Nov 0.5
R	*Euglena* spp.	Jul 1
A	Flagellates	

Table 7 con't.

	Species	Total monthly collections of rare forms at all stations
A	*Fragilaria capucina*	
R	*Fragilaria construens v. pumila*	Aug 0.5, Oct 1
A	*Fragilaria crotonensis*	
A	*Fragilaria intermedia*	
R	*Fragilaria intermedia v. fallax*	Apr 18, May 3
R	*Fragilaria leptostauron*	Apr 0.5
R	*Fragilaria pinnata*	Jun 3, Oct 3, Nov 8
R	*Fragilaria* spp.	Apr 27, Jun 6, Aug 2.5
R	*Franceia* spp.	Jul 0.5
A	*Glenodinium* spp.	
R	*Gloeocystis planktonica*	Jul 2, Sep 58
A	*Gloeocystis* spp.	
R	*Gomphonema* spp.	Apr 1, Jun 1, Sep 1
R	*Gomphosphaeria* spp.	Jun 1, Jul 1.5, Sep 43.5, Oct 1.5, Nov 4.5
R	green colonies	Apr 0.5
R.	green filaments	Apr 1.5, May 0.5, Jul 2, Sep 1, Oct 1, Nov 2
R	*Kirchneriella* spp.	May 0.5, Jun 17, Jul 8.5, Aug 1, Sep 1
R	*Lagerheimia* spp.	Jun 1
R	*Mallomonas pseudocoronata*	Oct 0.5
R	*Mallomonas* spp.	Jul 1.5, Aug 1, Sep 0.5
R	*Melosira distans*	Oct 11
A(r)	*Melosira granulata*	
A(r)	*Melosira granulata v. angustissima*	
A	*Melosira islandica*	
R	*Melosira italica*	May 37, Jun 43
A	*Melosira* spp.	
R	*Merismopedia elegans*	Sep 6, Oct 2
R	*Merismopedia* spp.	Sep 16
R	*Mougeotia* spp.	Apr 0.5
R(r)	*Navicula capitata*	Apr 0.5
R	*Navicula lanceolata*	Oct 0.5

Table 7 con't.

	Species	Total monthly collections of rare forms at all stations
R	*Navicula tripunctata*	Apr 0.5, Oct 5
R	*Navicula* spp.	Apr 4, May 2.5, Jun 7, Jul 0.5, Aug 5, Sep 1, Oct 1, Nov 4.5
R(r)	*Nitzschia acicularis*	Apr 1, May 1, Jun 2, Jul 0.5, Sep 2, Nov 7
R	*Nitzschia acuta*	Sep 0.5, Oct 3.5
R	*Nitzschia angustata*	Oct 2.5, Nov 2
R	*Nitzschia bacata*	Oct 15, Nov 7
R	*Nitzschia capitellata*	Oct 5
R	*Nitzschia confinis*	Jul 0.5, Sep 0.5, Oct 9.5, Nov 7.5
R	*Nitzschia dissipata*	Oct 1.5, Nov 1
R	*Nitzschia filiformis*	Oct 1
R	*Nitzschia fonticola*	Aug 0.5, Oct 1, Nov 3.5
R	*Nitzschia frustulum*	Aug 0.5, Oct 3
R	*Nitzschia palea*	Jul 9, Aug 2.5, Sep 1, Oct 12, Nov 8
R	*Nitzschia paleacea*	Jul 2
R	*Nitzschia* sp #1	Jun 1, Oct 3, Nov 4.5
R(r)	*Nitzschia* sp #2	Apr 0.5, Jun 24, Oct 1.5
A	*Nitzschia* spp.	
R	*Oedogonium* spp.	Apr 11.5, Jul 3, Sep 4, Nov 1
A	*Oocystis* spp.	
R	*Oscillatoria* spp.	Apr 3, Sep 1
R	*Pediastrum duplex*	Nov 1
R	*Pediastrum simplex*	Apr 0.5, Sep 0.5
R	*Pediastrum* spp.	Jun 4, Aug 3, Sep 1, Nov 0.5
R	*Peridinium* spp.	Apr 16, May 2, Jul 5, Aug 22.5, Sep 2.5
R	*Pinnularia* spp.	Sep 0.5, Nov 0.5
R	*Quadrigula lacustris*	Jul 0.5
R	*Rhizosolenia eriensis*	Apr 2, Jul 0.5, Nov 0.5
A	*Rhizosolenia gracilis*	
A	*Rhizosolenia* sp (unidentified)	
R	*Rhoicosphenia curvata*	Jun 1

Table 7 con't.

	Species	Total monthly collections of rare forms at all stations
R	*Scenedesmus abundans*	Jun 4, Aug 9, Sep 2, Nov 4
R	*Scenedesmus bicellularis*	Aug 2, Oct 2, Nov 6
R	*Scenedesmus bijuga*	Jun 3
R	*Scenedesmus dimorphus*	Jun 3, Oct 7, Nov 1
R	*Scenedesmus falcatus*	Oct 9
R	*Scenedesmus longus*	Jun 2
R	*Scenedesmus opoliensis v. contracta*	Jun 1
A	*Scenedesmus quadricauda*	
A	*Scenedesmus* spp.	
R	*Schroederia* spp.	Sep 2.5
R	*Sorastrum spinulosum*	Jul 0.5
R	*Sphaerocystis* spp.	Jul 0.5, Sep 22, Oct 2.5, Nov 4
R	*Spirogyra* spp.	Oct 1, Nov 0.5
A	*Stephanodiscus alpinus*	
R	*Stephanodiscus astraea*	Aug 3, Oct 4.5, Nov 0.5
R	*Stephanodiscus binderanus*	Jul 0.5
R	*Stephanodiscus hantzschii*	Jul 0.5, Aug 21.5, Oct 18, Nov 31
R	*Stephanodiscus minutus*	Jul 2, Aug 25.5, Oct 35, Nov 37.5
R	*Stephanodiscus niagarae*	Aug 1, Oct 3
R	*Stephanodiscus subtilis*	Aug 2, Oct 3.5, Nov 14.5
R	*Stephanodiscus tenuis*	Aug 4, Oct 23.5, Nov 10.5
R	*Stephanodiscus transilvanicus*	Apr 4, May 13, Jun 28
A	*Stephanodiscus* spp.	
R	*Surirella angustata*	Apr 4, May 4.5, Jun 26, Aug 2.5, Sep 1, Oct 6, Nov 2.5
R	*Surirella ovata v. pinnata*	Oct 1
R	*Synedra acus*	Oct 0.5, Nov 2.5
R	*Synedra delicatissima v. angustissima*	Nov 2
R	*Synedra demerarae*	Oct 1, Nov 0.5
R	*Synedra filiformis*	Apr 0.5, Nov 1.5
R	*Synedra ostenfeldii*	Oct 0.5, Nov 1

	Species	Total monthly collections of rare forms at all stations
A(r)	*Synedra ulna*	
R	*Synedra ulna v. chaseana*	Oct 11
R	*Synedra ulna v. longissima*	Nov 0.5
R	*Synedra* spp.	Apr 18, May 22.5, Jun 18, Sep 3, Oct 1
R	*Synura* spp.	Sep 1.5
A	*Tabellaria fenestrata*	
R	*Tetraedron caudatum*	Jun 1, Nov 0.5
R	*Tetraedron minimum*	Jun 5, Jul 4.5, Aug 3.5, Sep 0.5, Oct 1.5, Nov 0.5
R	*Tetraedron* spp.	May 0.5, Jun 2, Aug 3
R	*Tetrastrum staurogeniaeforme*	Oct 0.5
R	*Trachelamonas* spp.	Aug 0.5
R	*Ulothrix* spp.	May 0.5

Table 8. Monthly dominant forms and their abundance in the phytoplankton population in the monthly collections at the Cook Plant in 1972.

MONTH	DOMINANT FORMS	% OF POPULATION
April	*Tabellaria fenestrata*	33%
May	*Tabellaria fenestrata*	29%
June	*Cyclotella* spp.	28%
	Stephanodiscus spp.	23%
July	*Tabellaria fenestrata*	21%
August	*Fragilaria crotonensis*	37%
September	*Chroococcus* spp.	35%
October	*Melosira granulata*	35%
November	*Fragilaria crotonensis*	26%
	Tabellaria fenestrata	26%

Table 9. Total numbers of cells per milliliter, total numbers of forms collected, and mean numbers of cells per form by stations and months in the 1972 Cook Plant phytoplankton collections.

	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
APRIL									
cells/ml	1,056	1,139	-	929	964	997	792	716	133
no. forms	38	22	-	26	37	38	42	36	19
cells/form	28	52	-	36	26	26	19	20	7
MAY									
cells/ml	1,231	2,060	624	1,364	1,035	1,316	946	668	426
no. forms	25	30	22	27	34	26	26	21	32
cells/form	49	69	28	51	30	51	36	32	13
JUNE									
cells/ml	1,043	1,166	4,762	1,175	627	453	698	742	696
no. forms	16	30	29	33	30	19	31	27	26
cells/form	65	39	164	36	21	24	23	27	27
JULY									
cells/ml	173	202	-	156	355	134	66	218	182
no. forms	26	18	-	18	35	27	21	21	18
cells/form	7	11	-	9	10	5	3	10	10
AUGUST									
cells/ml	450	335	555	-	394	323	379	661	1,698
no. forms	32	31	27	-	36	27	26	29	28
cells/form	14	11	21	-	11	12	15	23	61
SEPTEMBER									
cells/ml	325	486	348	-	360	414	453	673	675
no. forms	28	36	35	-	24	28	22	22	19
cells/form	12	14	10	-	15	15	21	31	36

Table 9, cont'd.

	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
OCTOBER									
cells/ml	1,933	1,186	-	-	2,089	1,037	1,300	478	783
no. forms	48	41	-	-	41	47	41	34	26
cells/form	40	29	-	-	51	22	32	14	30
NOVEMBER									
cells/ml	1,662	805	2,748	-	586	1,619	625	239	519
no. forms	49	48	24	-	41	51	34	28	38
cells/form	34	17	115	-	14	32	18	9	14

bers of forms, and increased mean numbers of cells per form were typical of these months.

In addition to the contents of Table 9, there were other considerations in the choice of months for seasonal sampling: 1) April is the earliest month when ice conditions dependably allow us to operate a boat-borne survey; and 2) in the absence of evidence to the contrary, seasonal samplings should be on a three month spacing to enable the sampling of similar parts of the seasons. In accordance with these constraints, April, July, and October appear preferable as sampling months.

Table 9 indicates that collections in April 1972 caught a part of the spring bloom. July 1972 sampled the summer low of numbers. October 1972 samples were in the fall rise of numbers. On the evidence available, it appears that April, July, and October seasonal samplings are adequately representative of the spring, summer, and fall phytoplankton conditions.

Section 2. Biomasses, numbers and cell weights of Lake Michigan phytoplankton

John C. Ayers and Erwin Seibel

Introduction

This study has been prompted by present concerns about the quantities of phytoplankton which will pass through the Cook Plant. It attempts to provide the best possible figures available at present for 1) the average mass per unit volume, 2) the mean number of cells per unit volume, and 3) the approximate average weight of one phytoplankter. These figures, along with flow rates and percent of cells damaged, permit the refinement of previous estimates of phytoplankton damage due to plant passage.

The approach taken has been to obtain new data and to compare that data to information already established in the literature. The comparison of the present new data to already established data was carried out to place the present data into perspective with the limited array of information available on the subject.

The new data are derived from collections made on three transects of southern Lake Michigan in 1971 and 1972 by a project on the algal quality of Lake Michigan under the direction of Dr. Eugene F. Stoermer. These are supplemented by data from collections made at the Cook Plant in 1970. The transects used by the Stoermer project run east-west across the lake from South Haven and St. Joseph and roughly north up the center of the lake from Burns Harbor. In each transect stations are logarithmically spaced by distance from shore. The transects are shown in Figure 2. All collections were made by Nansen or Nisken bottles; Stoermer's collections were from the whole water column, those at the Cook Plant were from one meter.

Extensive use has been made of particle counts made on the Stoermer collections.

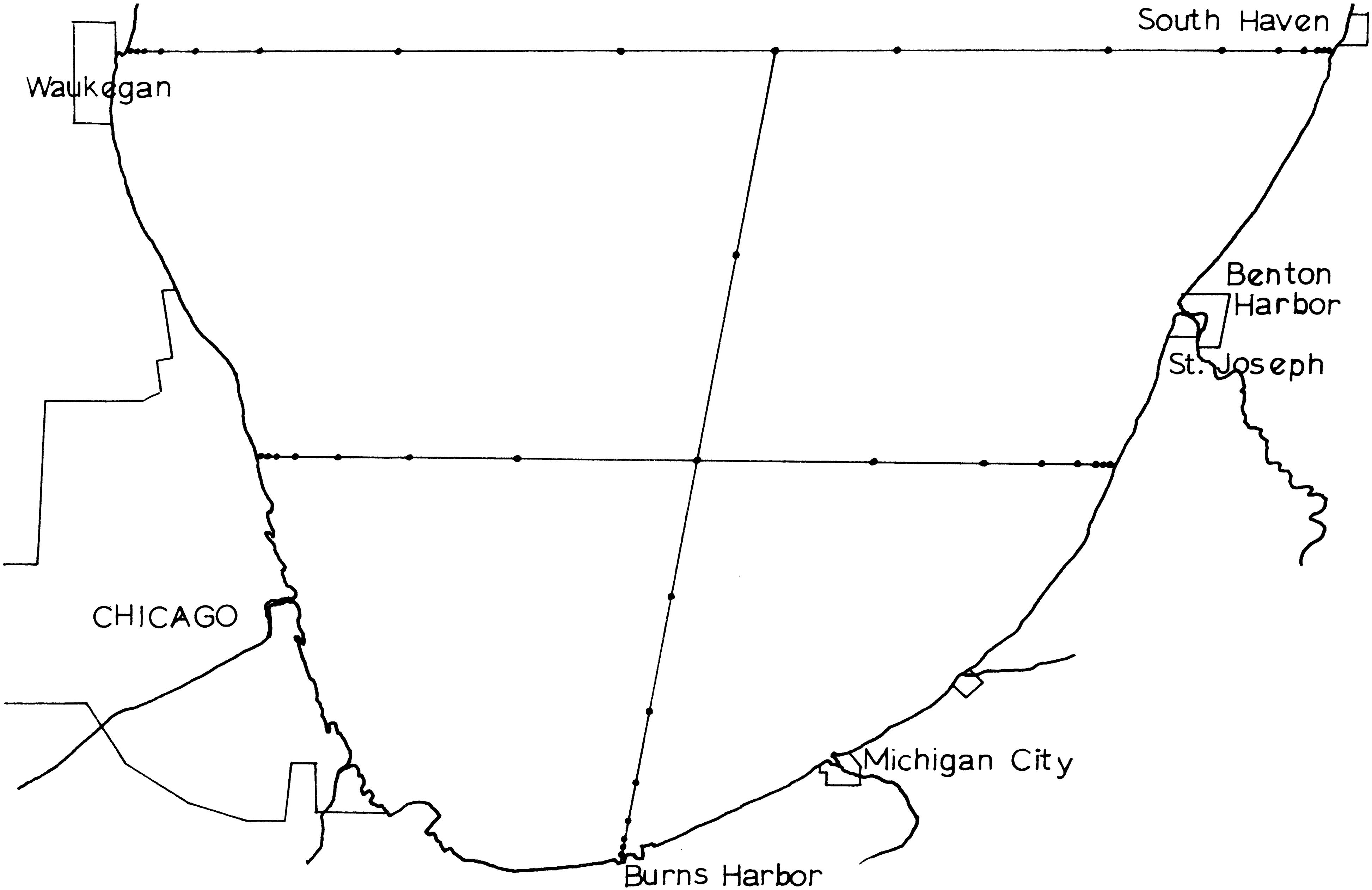

Figure 2. Stoermer's stations 1971-72.

Methodology

The particle counts were made with a HIAC-'SS' Automatic Particle Counter manufactured by High Accuracy Product Corporation of Claremont, California. The 120 ml sample bottles were vigorously shaken 30 times by hand, inverted, and allowed to sit for three minutes. The inversion of the bottle and the period of rest permitted air bubbles to escape from the sample prior to counting. After three minutes sitting the bottle was righted and 100 ml were counted at the manufacturer's recommended rate of 80 ml/minute. The shaking prior to counting breaks up coagulated particles and phytoplankton clumps, giving reproducibility of counts not obtainable with unshaken samples. Unfortunately the particle counter blindly counts sediment particles and particles of detritus which it cannot distinguish from phytoplankton; it is consequently necessary to apply corrections to the raw counts from the machine. In addition, the counter attains maximum efficiency at only a given maximum sample-feed rate. Results from the particle counter must be used with the knowledge that the method contains inherent errors to be guarded against and corrected for.

In weight determinations, Stoermer's transect collections of March, April, and May 1972 were separated into onshore and offshore groups at a point 8 miles from shore. The 8 mile distance was chosen on the basis that chlorophyll values showed relative constancy for stations 8 miles or more from shore (see Figure 3 where chlorophyll values and the 8 mile distance are shown). The previously counted inshore and offshore samples were separately filtered by transect through air-dried preweighed Whatman No. 42 filter papers which were then air-dried under cover in the laboratory for 30 days, being weighed every third day until constant weight was reached. Weighings were made on a Mettler H54 Analytical Balance correct to the nearest microgram manufactured by Mettler Instruments AG of Zurich, Switzerland. Air

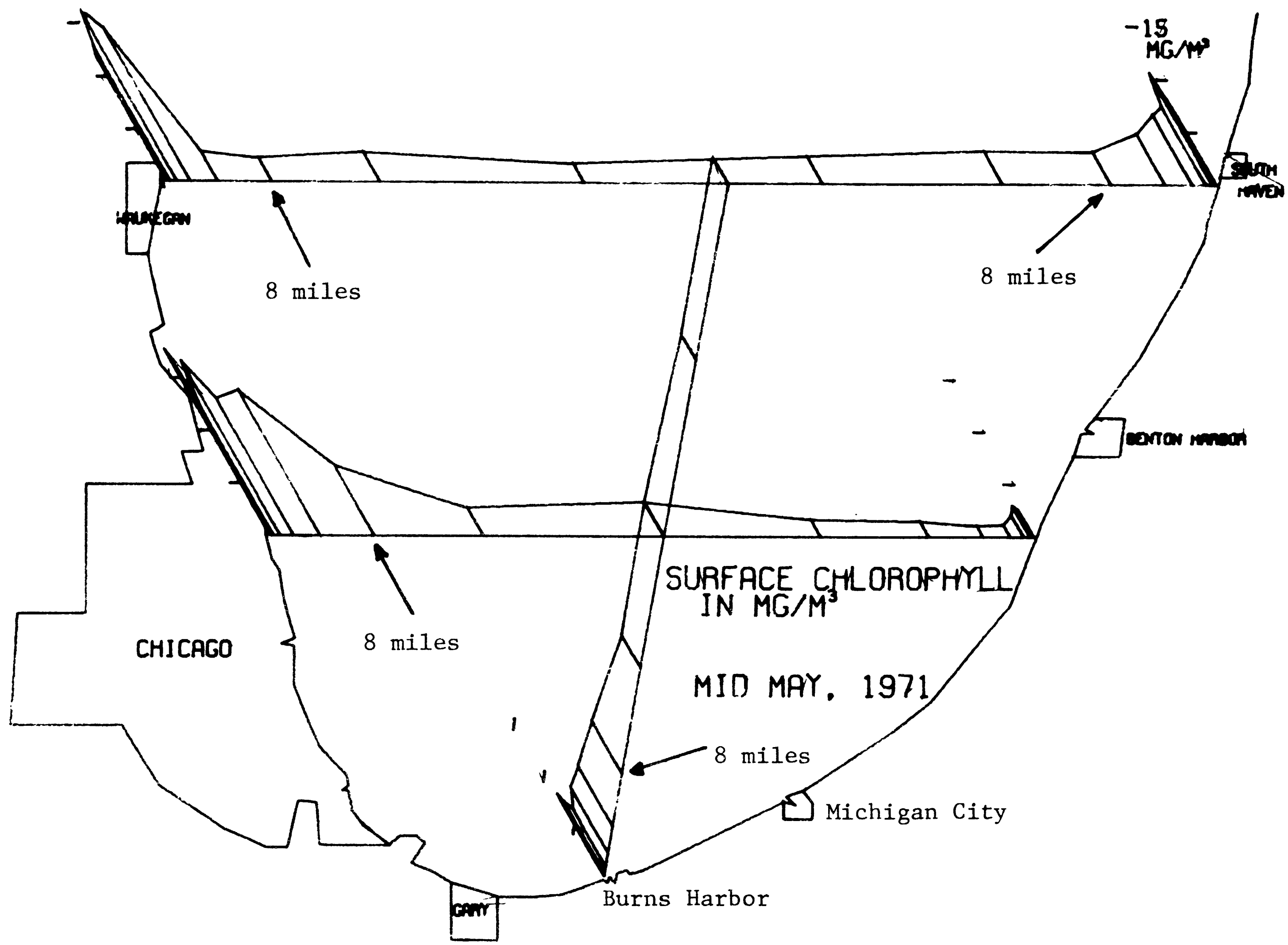

Figure 3. Chlorophyll, micrograms/m^3. May 1971.

drying was deliberately selected to avoid oven decomposition of bicarbonate particles, and to leave the filtered samples conservatively large.

Results and Discussion

Mass per Unit Volume Determinations

The mass per unit volume determinations for the months of March, April, and May 1972 were made on the inshore and offshore samples by using the dry weights of the samples and adjusting these weights to reflect the percentage of living phytoplankton to be expected in a typical sample of the season.

Robertson, Powers, and Rose (1971) showed that the dry weight of the sample when multiplied by the percent non-ash fraction gives an estimate of the particulate organic matter, and further, that to obtain the mass of living phytoplankton in the sample one must either subtract the estimated amount of detritus or multiply the amount of particulate organic matter by the percentage of live phytoplankton present. The latter procedure is used in obtaining the mass per unit-volume for the samples in this study and for the data presented by Powers et al. (1967).

From Robertson et al. (1971) an estimate of the average percent of living phytoplankton in a given sample can be obtained. Their average sample contained 36.4% living phytoplankton, while the range was from 11.8% to about 55% with the highest values occurring in May and November and consistently lower values during the summer months. The overall average mass/volume of living phytoplankton for their cruises in 1967 was 0.33×10^{-3} grams per liter.

Stoermer (1968), using a completely different technique, found that the average mass/volume of phytoplankton in the vicinity of Grand Haven, Michigan, was about 0.48×10^{-3} g/1.

Table 10 presents the data of the present study on samples from the spring

Table 10. Derivation of phytoplankton biomass per liter in 1972 inshore and offshore stations of Stoermer in southern Lake Michigan. Initial dry weight is of counted particles from Stoermer's collections.

I-0 *	Dry weight g x 10^{-3}	Ash-free dry weight ** g x 10^{-3}	Phytoplankton wt. at 55%*** g x 10^{-3}	Liters filtered	Phytoplankton g x 10^{-3}/liter	Transect
I	2.34	1.81	0.99	4.19	0.2387	South Haven (March & April)
O	0.95	0.73	0.40	5.95	0.0672	
I	6.64	5.13	2.82	4.19	0.6730	
O	2.59	2.00	1.10	6.00	0.1833	
I	5.20	4.02	2.21	3.70	0.5973	St. Joseph (March & April)
O	0.32	0.25	0.14	4.60	0.0304	
I	5.05	3.90	2.15	3.50	0.6143	
O	1.07	0.83	0.45	4.60	0.1000	
I	2.96	2.29	1.26	1.99	0.6332	Burns Harbor (March, April & May)
O	0.80	0.62	0.34	4.19	0.0811	
I	5.61	4.34	2.39	2.10	1.1381	
O	2.43	1.88	1.03	4.30	0.2395	
I	2.52	1.95	1.07	2.10	0.5095	
O	2.39	1.85	1.02	4.39	0.2323	
				OVERALL AVE.	0.3813	

*I = inshore stations; O = Offshore stations.

** = Dry weight x 0.7728 from Nalewajko (1966), to give average ash-free dry weight (organic tissue) from total dry weight.

*** = May average percent of particulate matter representing live phytoplankton (see text).

of 1972. A correction factor from Robertson et al. has been applied to these data: their May average that 55% of particulate matter was living phytoplankton. Since the present data are from the spring, the 55% average is considered more applicable than their overall 36.4%.

Table 11 summarizes the data of Powers et al. (1967) for the years 1964, 1965, and part of 1966. Their overall average weight/volume of phytoplankton was 0.33×10^{-3} g/l.

The available average values of phytoplankton mass/volume are then:

Powers et al. (1967)	0.33×10^{-3} g/l
Stoermer (1968)	0.48×10^{-3} g/l
Robertson et al. (1971)	0.33×10^{-3} g/l
Ayers, Seibel (this study)	0.38×10^{-3} g/l

Despite differences in techniques and data treatment, there is close agreement between the results of the four investigator teams.

Phytoplankton Number per Milliliter Determinations

In this section, as in the one before, present data are compared to existing literature data. The present data consist of corrected whole water column spring 1972 particle counts from the inshore and offshore stations of Stoermer's algal water quality of Lake Michigan project. For comparison against these data there are: 1) whole water column particle counts for similar stations in lower Lake Michigan in 1962 and 1963 (U. S. Dept. Interior, FWPCA, 1968); 2) Ayers et al. (1971) one-meter microscopic counts from 54 stations in a 7-mile radius of the Cook Plant in July 1970; 3) unpublished microscopic counts from the surface two meters for inshore and offshore stations of Stoermer's algal water quality of Lake Michigan project in 1971; 4) State of Illinois (1971) inshore plankton counts from 1970; and 5) plankton counts of Damann (1966) from Chicago and Milwaukee water plants.

Table 11. Dry weight phytoplankton biomass per liter in multi-seasonal cruises of Powers et al.

DEPTH	0-25 m			>25 m		
	Particulate matter mg/l	Ash free mg/l	Phyto * mg/l	Particulate matter mg/l	Ash free mg/l	Phyto * mg/l
Apr.-Nov. 1964	2.055	0.990	0.3603	1.847	0.874	0.3181
Apr.-Nov. 1965	2.163	1.043	0.3796	1.927	0.860	0.3130
Mar.-Jun. 1966	2.560	0.969	0.3527	2.165	0.765	0.2784
AVE.	2.259	1.0007	0.3642	1.980	0.833	0.3032

All-depth ave. Weight/volume of Phytoplankton = 0.3336×10^{-3} g/l

*Phytoplankton mg/l obtained by multiplying Ash Free Weight/Volume by 36.4% ave. living phytoplankton in a sample.

Table 12 presents the results obtained by the present study for numbers of phytoplankters per milliliter in spring 1972. The correction factor -- 55% of particles are phytoplankton, from Robertson et al. -- was applied to the particle counts. The two-month overall average for inshore stations was 1317 phytoplankters per milliliter, that for offshore stations was 443 per ml.

Table 13 shows the data reported by FWPCA for southern Lake Michigan stations in spring, summer, and fall of 1962 and 1963. No correction factor has been applied to these data as they are given as "Phytoplankton, numbers per milliliter." Their inshore stations showed spring counts of 1125 cells/ml (1962), 1639 cells/ml (1963), and an overall 3-season average of 1443 cells/ml. Offshore stations had spring counts of 1168 cells/ml (1962), 416 cells/ml (1963), and an overall 3-season average of 565 cells/ml.

Ayers et al. (1971) at 54 inshore stations around the Cook Plant obtained an overall average of 1256 cells/ml in July 1970.

The results of microscopical counts of phytoplankton from collections of Stoermer's cruises during 1971 are given in Table 14; these counts are from the upper two meters only and cannot reflect possible lower counts in the subsurface water layers as would his whole water column particle counts (Table 12) and those of the FWPCA (Table 13). Stoermer's results give for inshore stations 4097 cells/ml with a 3-season average of 3013 cells/ml (spring), 2160 cells/ml (summer), and 2782 cells/ml (fall). His offshore stations give 1281 cells/ml (spring), 1062 cells/ml (summer), and 1855 cells/ml (fall). It is now believed that Stoermer's higher inshore surface microscopical counts are a reflection of his station locations (1/4, 1/2, 1, 2, 4, and 8 miles from shore) with their inherent weighting of stations close inshore, as well as their inability to incorporate possible lower counts from the underlying water layers of the deeper stations.

Some confirmation of this is found in a September 1971 report from the

Table 12. Numbers of phytoplankton per milliliter from spring 1972 whole water column particle counts. Data of Stoermer, southern Lake Michigan.

		Total particle count	55% of Count	Volume filtered, ml	Number per ml	Transect
March 72	I*	8334267	4583846	4195	1093	South Haven
March 72	0*	3551419	1953280	5945	329	
April 72	I	9431024	5187063	4190	1238	
April 72	0	5811688	3196428	6000	533	
March 72	I	9915986	5453792	3700	1474	St. Joseph
March 72	0	3346962	1840829	4600	400	
April 72	I	7548626	4151744	3500	1186	
April 72	0	4008568	2204712	4600	479	
March 72	I	4595256	2527390	1990	1270	Burns Harbor
March 72	0	2793573	1536465	4195	366	
April 72	I	6273327	3450329	2100	1643	
April 72	0	4297765	2363770	4300	550	

	March	April	2 Month Ave.
Average Inshore	1279	1356	1317
(All Transects) Offshore	365	521	443

*I = Inshore stations; 0 = Offshore stations.

Table 13. Numbers of phytoplankton per milliliter in southern Lake Michigan in 1962-63. Data of FWPCA.

	Spring 62	Summer 62	Fall 72	Spring 63	Summer 63
SOUTH HAVEN					
Inshore	1503	1590	4453	2552	X
Offshore	1184	562	110	416	X
ST. JOSEPH					
Inshore	X	1143	2259	1210	X
Offshore	1153	291	577	X	X
BURNS HARBOR					
Inshore	748	171	418	1155	1106
Offshore	X	231	251	X	X
AVERAGE					
Inshore	1125	968	2377	1639	1106
Offshore	1168	361	313	416	X

X = no data for that location for that time.

Table 14. Numbers of phytoplankton per milliliter in southern Lake Michigan in 1971. Microscopical cell counts from surface two meters only.

	Cruise 1 31 March - 11 April	Cruise 2 13 May - 20 May	Cruise 3 12 June - 27 June	Cruise 4 14 July - 20 July	Cruise 5 24 August - 30 August	Cruise 6 14 September - 23 September	Cruise 7 7 October - 14 October	Cruise 8 25 October - 30 October
SOUTH HAVEN								
Inshore	4553	4645	1569	1503	1052	662	2912	2070
Offshore	1322	1135	935	1000	762	377	3330	1457
ST. JOSEPH								
Inshore	6949	2156	1610	899	1514	864	3894	4101
Offshore	1775	1090	1691	897	997	648	2559	2699
BURNS HARBOR								
Inshore	4602	1677	8083	1271	1936	1747	4911	3877
Offshore	1638	725	1635	705	937	982	3138	1507
	Spring '71			Summer '71			Fall '71	
Inshore	4097			2160			2782	
Offshore	1281			1062			1855	

All values are number of cells/ml.

Illinois Environmental Protection Agency. Their Table 17 reports annual average numbers of plankton organisms per milliliter for 1970 from 10 water filtration plants from Waukegan to South Chicago. Their averages range from 2200 to 3600 from which we have computed an overall average of 2990 organisms/ml for the relatively close inshore water intakes represented. On the other hand their Table 31 reports average annual 1970 surface plankton densities from 8 stations at positions 4 miles offshore from the Wisconsin-Illinois State Line to South Chicago. These averages range from 700 to 2000 organisms/ml from which we have calculated an overall average of 1200 organisms/ml. Stoermer's inshore microscopical counts (3013 cells/ml) closely resemble the counts at the water plant intakes, while his inshore particle counts (1317 cells/ml) resemble a median-distance mean inshore station. That the Illinois 4-mile station surface plankters could represent whole water column plankton densities is attributed to the upwind positions of the stations and to frequent upwellings.

Damann (1966) presents long-term average monthly plankton counts from water filtration plants at Chicago and Milwaukee. He obtained annual averages of 1018 at Chicago and 779 cells/ml at Milwaukee.

There are, then, available:

	Inshore	Offshore
FWPCA multiseasonal ave. 1962-63	1443	565
Stoermer (this study) spring 1972 ave.	1317	443
Stoermer 1971 multiseasonal ave.	3013	1399
Damann Chicago ave. 1928-45	1018	-
Damann Milwaukee ave. 1940-63	779	-
Illinois EPA multiseasonal ave. 1970	2990	1200
Averages	1760	902

Weight of an Average Individual Phytoplankter

From Stoermer's particle counts and our dry weights of his counted particles the weight of an average phytoplankter has been calculated. Again, the correction factor that 55% of spring particles are live phytoplankters has been used.

(Table 15) presents results of the calculations. The weight of an individual phytoplankter in the samples analysed ranged from 0.075×10^{-9} grams to 1.2×10^{-9} grams. Inshore stations commonly gave a higher weight per phytoplankter than did the offshore stations. The overall inshore station weight was 0.57×10^{-9} gm per individual, while the offshore individuals averaged 0.38×10^{-9} gm. The average of the two was 0.47×10^{-9} gm/cell.

The only valid comparison to literature values that was possible was with the laboratory data of Nalewajko (1966), who used 28 species of freshwater algae that correspond very well to the algal species of Lake Michigan. Nalewajko's results show cell weights ranging from 0.01×10^{-9} gm to 1.3×10^{-9} gm, with an overall average of 0.4×10^{-9} gm/cell. The range and average are in good agreement with our results.

As additional estimates, our 0.38×10^{-3} g/l of phytoplankton biomass (Table 10) was divided by Damann's long-term Chicago and Milwaukee plankton counts (1018 and 779 respectively) and also by the grand mean of inshore counts (1760) obtained in the preceeding section. The results with Damann's counts were 0.37×10^{-9} g/cell and 0.49×10^{-9} g/cell; with 1760 cells/ml we obtained 0.22×10^{-9} g/cell.

Table 15. Average weights of individual phytoplankters in southern Lake Michigan 1972. Data from Stoermer.

		Total Count	55% of Count	Dry weight g x 10^{-3}	weight/cell g x 10^{-9}	Transect
March 72	I*	8334267	4583846	0.99	[illegible]	
March 72	0*	3551419	1953280	0.40	0.206	South Haven
April 72	I	9431024	5187063	2.82	0.544	
April 72	0	5811688	3196428	1.10	0.344	
March 72	I	9915986	5453792	2.21	0.405	
March 72	0	3346962	1840829	0.14	0.075	St. Joseph
April 72	I	7548626	4151744	2.15	0.517	
April 72	0	4008568	2204712	0.45	0.205	
March 72	I	4595256	2527390	1.26	0.498	
March 72	0	2793573	1536465	0.34	0.222	Burns Harbor
April 72	I	6273327	3450329	2.39	0.692	
April 72	0	4297765	2363770	1.03	0.437	
May 72	I	1731466	952306	1.07	1.126	
May 72	0	1507533	829143	1.02	1.227	

AVERAGE

Inshore	0.571
Offshore	0.388

*I = Inshore stations; 0 = Offshore stations.

The results available are then:

	Inshore	Grams x 10^{-9} Ave.	Offshore
This study (Ayers and Seibel)	0.57	0.47	0.38
Nalewajko ave.		0.4	
Damann Chicago count ave.		0.37	
Damann Milwaukee count ave.		0.49	
0.38×10^{-3} over 1760		0.22	
Average		0.39	

As a magnitude check, the 0.33×10^{-3} gm/l average multiseasonal lake-wide phytoplankton weight per volume of Powers et al. (Table 11) was divided by the available multiseasonal inshore-offshore grand average number of cells per liter. Stoermer's data of Table 13 and the FWPCA data of Table 14 met the requirements. In each the multiseasonal inshore and offshore averages were averaged together, and then the averaged averages of the two were averaged. The resulting grand average (1605 cells/ml) was then divided into 0.33×10^{-3} gm/l. The quotient so obtained was 0.2×10^{-9} gm/cell, a common value in the present study results (see Table 15).

SUMMARY AND CONCLUSION

Considering the varying techniques which had to be used and the variability of phytoplankton, favorable comparison was found between the results of this study and the scanty similar results presented by other investigators.

Our results are:

1) the average weight of phytoplankton in the southern portion of Lake Michigan will range from about 0.09 to about 0.63 milligrams per liter of water. The average from this study is 0.38 mg/l.

2) The average numbers of phytoplankton in the whole water column in southern Lake Michigan will range from about 300 per ml to several thousand per ml. The results of this study indicate (Tables 12 and 13) average numbers of 1760 per ml for inshore stations and 900 per ml for offshore stations.

3) The average weight of a single "mean phytoplankter" in southern Lake Michigan was found to range from 0.075×10^{-9} gram to 1.2×10^{-9} gm. The average weight at inshore stations was 0.57×10^{-9} gm; that at offshore stations was 0.38×10^{-9} gm. The overall average from all available data was 0.39×10^{-9} g/cell.

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A.3 *Development of a Monitor for Phytoplankton*

Although never a specified requirement, we early envisioned the advantages of a system which simultaneously measured phytoplankton chlorophyll fluorescence and counted passing particles. In particular, we envisioned this system as reducing the necessity for huge numbers of samples for microscopical plankton counts with their unavoidable time lag to produce results. Our efforts in this direction have had some modest success but have been surpassed by the development of commercial fluorometers and particle counters. Because of these and rising pressures for expanded biological studies directly related to the Cook Plant, we have concluded that the development of a phytoplankton monitor as originally envisioned is partly unfeasible, partly unnecessary, and should be abandoned. This section will henceforth be ABANDONED.

A.4 *Study of Attatched Algae*

Erwin Seibel, Nancy Schrank, and Susan L. Williams

Introduction

This portion of the report continues the reporting of data on periphyton begun last year. A total of four periphyton collectors, each bearing duplicate collecting surfaces (see Figure 4), were set in water depths of 15 and 30 feet along the north and south property boundaries of the Donald C. Cook Nuclear Power Plant site.

We had planned to collect the periphyton samples by changing the collector blocks each month. While blocks were removed each month from May through November, not all locations provided samples. The surface buoys for both of the southern locations sank and were not recovered, preventing sampling at these sites. In addition, the surface buoy at the 30 foot depth at the north boundary was lost by September, preventing data here after that time. Problems encountered in removing the periphyton from its substrate resulted in the absence of data for the months of May, June, and August as far as the weight calculations were concerned. For the identification of the periphyton, a different technique which worked well for all months was used. This technique and data are presented later in this section.

Method

As was noted above, problems were encountered in removing the periphyton from the substrate for weighing purposes. We undertook a study to find the solvent most efficient in the removal process and finally concluded that benzene was the most effective solvent of the styrofoam.

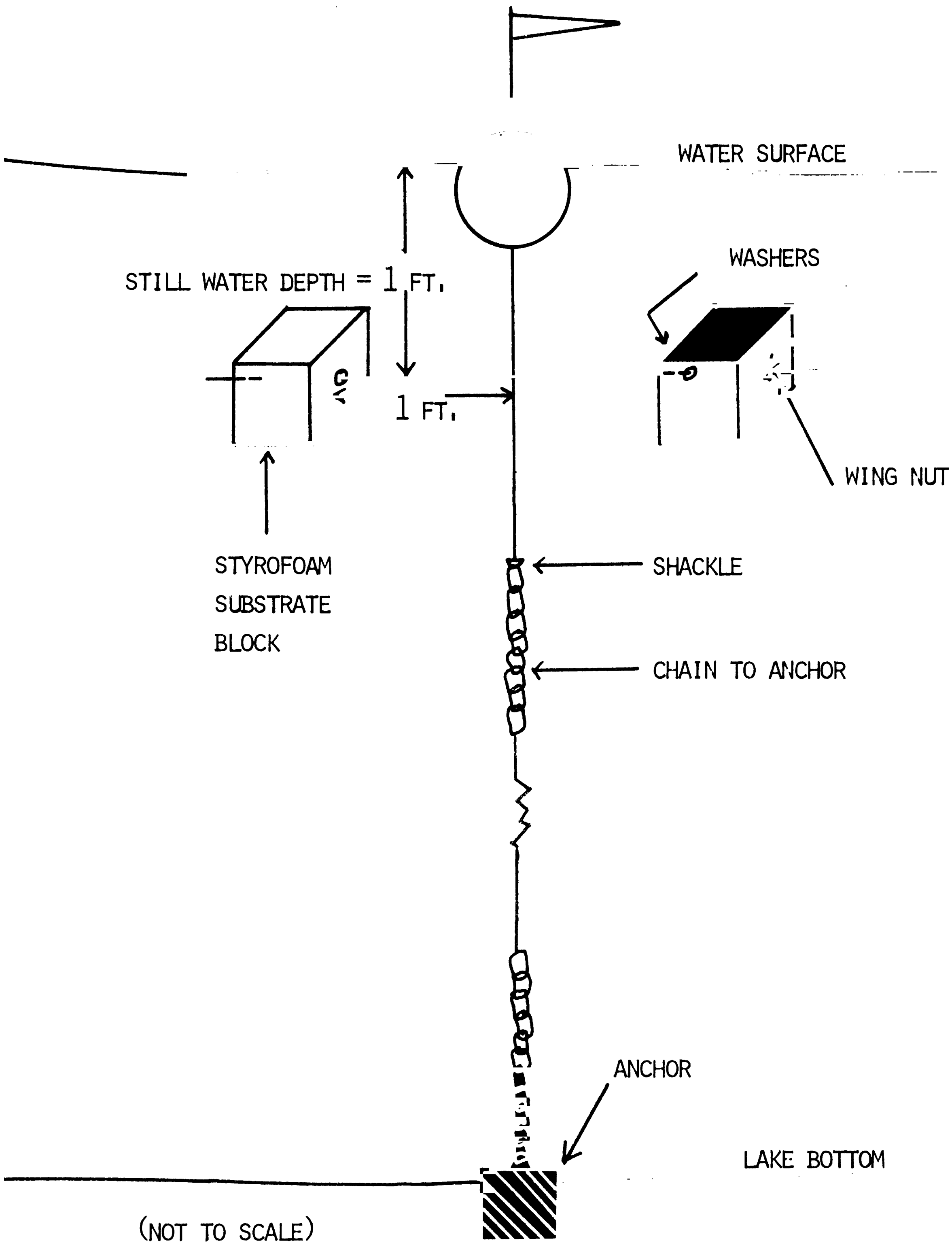

Figure 4. Schematic representation of typical periphyton collector site.

Styrofoam collection blocks were removed from the collectors in the field and frozen. Small square food-freezing plastic containers with an inner bottom of plywood and a central upright nail were used for freezing. The sample blocks were dropped over the nails and kept from contacting the container sides.

The method which was adopted for separating the periphyton from the styrofoam blocks is presented below. The frozen styrofoam blocks were removed from the freezer and the dimensions of all sides were taken. Using a microtome knife, thinly sliced portions of the styrofoam-periphyton were placed into a 100 ml beaker and allowed to sit for about thirty minutes (usually sufficient time to dry the sample under an air hood). 100 ml of benzene were then added to the sample; once the styrofoam was dissolved the sample was drawn through a preweighed glass fiber filter separating the styrofoam-benzene solution from the periphyton. The sample in the funnel was rinsed with 200 ml of benzene to assure total removal of the styrofoam and to wash the periphyton from the funnel walls onto the filter. The filter was then air dried and weighed. Since benzene was used, the entire process just described was done under an air hood for safety.

Discussion and Results

The information obtained monthly was:

a. Periphyton weight per side of the styrofoam block

b. Dimensions and areas of the collecting surfaces

c. Total periphyton weight per block

d. Weight/area of each collecting surface

e. Weight/area of the total collecting surfaces

which indicated the apparent average periphyton growth per month.

The data for the four months in which data were obtained are tabulated in Table 16. Two things are evident upon analysis of the data. First, one side of the styrofoam block consistently had a higher weight and weight/area ratio than the other sides. Two sides had similar weights while the final collecting surface was generally lower. It is suggested that the collecting surface having the greatest weight is the one that faces upward, while the one having the lowest weight and, therefore, the lowest concentration of periphyton should be the collecting side that faces the lake bottom. Second, the samples of July and September had similar weight/area ratios while the samples collected in the beginning of October and November showed a higher weight/area ratio.

In one sense the data are limited in that they are from north of the plant alone, which prevents a comparison of the data north and south as was initially intended. The next field season's data will hopefully allow for a north-south location comparison.

Species Identification

Preparation of Periphyton Slides: Diatoms are removed from the styrofoam substrate by a reaction of hydrogen peroxide and potassium dichromate. The blocks are placed into a beaker, and hydrogen peroxide, which has attained room temperature, is then added. Enough hydrogen peroxide is poured into the beaker to cover the block as it is submerged by a metal weight. Some floating of the styrofoam block does occur, but the reaction of the hydrogen peroxide will cover all surfaces sufficiently to enhance the removal of the periphyton from the substrate. A few crystals of potassium dichromate are added at a time as the beaker is swirled. The addition of potassium di-

Table 16. Collectors' areas, dry weights, weight/area ratio, and apparent average monthly growth of periphyton off the Cook Plant.

Date and Identification	Side	Area of Collecting Side cm^2	Dry Weight of Periphyton mg	W/A mg/cm^2
16 Jul 72 N30A	1	33.15	58.56	1.76
	2	32.64	47.18	1.44
	3	31.50	46.43	1.47
	4	32.00	35.57	1.11
	Total	129.29	187.74	1.45*
16 Jul 72 N15A	1	32.00	87.44	2.73
	2	33.15	61.43	1.85
	3	33.50	39.86	1.18
	4	34.68	52.37	1.51
	Total	133.33	241.10	1.80*
10 Sep 72 N15A	1	32.13	50.25	1.56
	2	32.13	38.17	1.18
	3	32.13	25.07	0.78
	4	31.11	35.49	1.14
	Total	127.50	148.98	1.16*
6 Oct 72 N15A	1	30.00	225.83	7.52
	2	32.00	42.21	1.31
	3	31.11	39.93	1.28
	4	31.50	45.00	1.42
	Total	124.61	352.97	2.83*
1 Nov 72 N15A	1	31.50	804.03	25.52
	2	32.00	182.74	5.71
	3	31.50	104.92	3.33
	4	31.50	294.38	9.34
	Total	126.50	1386.13	10.95*

*Apparent average periphyton growth, mg dry weight/cm^2/month.

chromate speeds up the reaction. Sufficient potassium dichromate has been added when the mixture turns dark in color and bubbles slightly; usually much less than one gram is sufficient to produce these results. Excessive amounts of potassium dichromate cause the mixture to boil over the beaker which may result in a loss of periphyton. The reaction is considered complete when the color of the solution turns a deep yellow.

Once the block has been removed, the diatoms are permitted to settle for six or more hours. The liquid is now poured off, taking particular care not to lose any of the settlement. Distilled water is then added to the sediment and swirled and again allowed to sit. This process is repeated until the water remains clear and is without a yellow tint.

The mounting of the periphyton is as follows: suspend the sediment in distilled water, with the use of a dropper spread the sediment-water mixture onto a cover slip, and allow the water to evaporate. Once the water has evaporated, bake the cover slip on a hot plate set at 450 Watts for about ten minutes, following which place a drop of HYRAX in the middle of a labeled slide and place the cover slip, sediment side down, on the drop. Again, place the slide on the hot plate and leave it there until all the toluene has been boiled from the HYRAX. Then remove the slide and cover slip from the hot plate and reposition the cover slip, which may have moved in the boiling process, in the center of the slide, and gently tap it downward. The slide is now ready for examination under the oil immersion Leitz Ortholux Microscope using 1000X magnification.

The species identifications for the months of May, June, July, August, and October are presented in Table 17. The September slides did not permit counting. As observed, the species of diatom periphytes increases from May through October. There was no indication of *Cladophora* on the collecting blocks.

Table 17. Periphyton species lists. Sample N15B, May 1972.

Achnanthes sp.
Asterionella formosa
Cyclotella Kützingiana
Cyclotella meneghiniana v. plana
Cyclotella michiganiana
Cyclotella ocellata
Cyclotella pseudostelligera
Cyclotella stelligera
Cymbella ventricosa (Kütz)
Cymbella sp.
Diatoma tenue v. elongatum
Fragilaria capucina
Fragilaria construens v. minuta
Fragilaria crotonensis
Fragilaria intermedia
Fragilaria pinnata v. lanceettula
Gomphonema olivaceum
Gomphonema sp.
Melosira granulata
Melosira islandica
Melosira italica
Navicula cryptocephala
Navicula decussis
Navicula latens
Navicula menisculus
Navicula menisculus v. upsaliensis
Navicula nyassensis fo. minor
Navicula radiosa
Navicula tripunktata
Navicula sp.
Neidium dubium
Nitzschia acicularioides
Nitzschia acicularis
Nitzschia confinis
Nitzschia dissipata
Nitzschia longissima v. reversa
Nitzschia palea
Nitzschia sp. (our #6)
Stephanodiscus alpinus
Stephanodiscus binderanus
Stephanodiscus hantzschii
Stephanodiscus minutus
Stephanodiscus tenuis
Stephanodiscus sp. (our #5)
Surirella angustata
Synedra amphicephala
Synedra delicatissima
Synedra filiformis
Synedra minuscula
Synedra ostenfeldii
Synedra rumpens
Synedra ulna
Synedra vaucheriae
Tabellaria fenestrata

Very common species	Common species	Rare species
Diatoma tenue v. elongatum	*Asterionella formosa*	*Achnanthes* sp.
Synedra minuscula	*Gomphonema olivaceum*	*Navicula nyassensis f. minor*
Synedra vaucheriae		*Neidium dubium*
		Nitzschia longissima v. reversa
		Stephanodiscus alpinus
		Surirella angusta

May periphyton slides were the first periphyton to be made and there was much air in the diatoms, making them hard to identify. There also was an unusual number of girdle views.

Table 17 con't. Sample N30B, June 13, 1972.

Achnanthes lanceolata v. dubia
Amphipleura pellucida
Amphora ovalis
Asterionella formosa
Cocconeis diminuta
Cocconeis placentula
Cyclotella meneghiniana
Cyclotella meneghiniana v. plana
Cyclotella michiganiana
Cyclotella ocellata
Cyclotella operculata
Cyclotella stelligera
Cybella sinuata f. ovata
Cymbella subventricosa
Diatoma tenue v. elongatum
Diatoma vulgare
Fragilaria brevistriata
Fragilaria brevistriata v. inflata
Fragilaria construens v. minuta
Fragilaria intermedia
Gomphonema angustatum
Gomphonema olivaceum
Gomphonema parvulum
Hantzschia amphioxys
Melosira granulata
Melosira islandica
Melosira italica
Navicula capitata
Navicula cryptocephala
Navicula cryptocephala v. intermedia
Navicula cryptocephala v. veneta
Navicula decussis
Navicula gastrum
Navicula gregaria
Navicula lanceolata
Navicula menisculus v. upsaliensis
Navicula micropupula
Navicula minuscula
Navicula mutica v. cohnii
Navicula rhyncocephala
Navicula seminulum
Navicula tripunktata
Navicula viridula
Navicula viridula v. avenacea
Neidium dubium
Nitzschia acicularis
Nitzschia acuta
Nitzschia bacata
Nitzschia confinis
Nitzschia dissipata
Nitzschia fonticola
Nitzschia thermalis v. minor
Nitzschia sp. (our #1)
Rhoicosphenia curvata
Stephanodiscus alpinus
Stephanodiscus binderanus
Stephanodiscus hantzschii
Stephanodiscus minutus
Stephanodiscus subtilis
Stephanodiscus tenuis
Synedra capucina
Synedra filiformis
Synedra minuscula
Synedra ostenfeldii
Synedra rumpens
Synedra ulna
Synedra vaucheriae
Tabellaria fenestrata

Very common species

Asterionella formosa
Diatoma tenue v. elongatum
Navicula gregaria
Navicula cryptocephala
Navicula viridula
Nitzschia dissipata
Stephanodiscus minutus
Synedra capucina
Synedra rumpens
Synedra minuscula
Synedra ulna
Synedra vaucheriae
Tabellaria fenestrata

Rare species

Achnanthes lanceolata v. dubia
Amphipleura pellucida
Cyclotella operculata
Cymbella sinuata f. ovata
Hantzschia amphioxys
Navicula mutica v. cohnii
Nitzschia thermalis v. minor
Rhoicosphenia curvata
Stephanodiscus binderanus

Table 17 con't. Sample N30B, July 16, 1972.

Achnanthes affinis
Achnanthes clevei v. rostrata
Achnanthes exigua
Achnanthes haukiana v. rostrata
Achnanthes lanceolata v. elliptica
Achnanthes linearis
Achnanthes minutissima
Amphipleura pellucida
Amphora ovalis
Amphora sp.
Asterionella formosa
Cocconeis placentula
Coscinodiscus subsalsa
Cyclotella comta
Cyclotella Kutzingiana
Cyclotella Kutzingiana v. radiosa
Cyclotella meneghiniana v. plana
Cyclotella michiganiana
Cyclotella ocellata
Cyclotella pseudostelligera
Cyclotella stelligera
Cymatopleura solea v. apiculata
Cymbella affinis
Cymbella microcephala
Cymbella prostrata
Cymbella subventricosa
Cymbella turgida
Diatoma tenue v. elongatum
Diatoma vulgare v. breve
Diploneis parma
Epithemia sp.
Fragilaria brevistriata v. inflata
Fragilaria capucina
Fragilaria construens
Fragilaria construens v. binodis
Fragilaria crotonensis
Fragilaria intermedia
Fragilaria leptostauron
Fragilaria pantocsekii v. binodis
Fragilaria parasitica
Fragilaria pinnata
Fragilaria vaucheriae v. truncata
Gomphonema intricatum
Gomphonema olivaceoides
Gomphonema olivaceum
Gomphonema parvulum
Gomphonema subclavatum
Gyrosigma spencerii v. curvala
Melosira granulata
Melosira islandica
Melosira italica
Meridion circulare
Navicula capitata
Navicula capitata v. luneburgensis
Navicula cryptocephala
Navicula gastrum v. signata
Navicula gregaria
Navicula grimmei
Navicula integra
Navicula menisculus
Navicula menisculus v. upsaliensis
Navicula menicropupula
Navicula nyassensis f. minor
Navicula platystoma v. pantocsekii
Navicula radiosa v. tenella
Navicula reinhardtii
Navicula rhyncocephala
Navicula similis
Navicula tripunktata
Navicula tuscula f. rostrata
Navicula viridula v. avenacea
Navicula sp. (our #78)
Neidium dubium
Nitzschia acicularis
Nitzschia angustata v. acuta
Nitzschia apiculata
Nitzschia bacata
Nitzschia capitellata
Nitzschia confinis
Nitzschia dissipata
Nitzschia fonticola
Nitzschia hungarica
Nitzschia insecta
Nitzschia Kutzingiana
Nitzschia macilenta
Nitzschia palea
Nitzschia recta
Nitzschia spiculoides
Nitzschia vexans
Nitzschia sp. (our #1)
Nitzschia sp. (our #2)
Nitzschia sp. 1
Nitzschia sp. 2

Table 17 con't. Sample N30B, July 16, 1972 con't.

Stephanodiscus alpinus
Stephanodiscus astraea
Stephanodiscus binderanus
Stephanodiscus hantzschii
Stephanodiscus minutus
Stephanodiscus subtilis
Stephanodiscus tenuis
Stephanodiscus transilvanicus
Surirella angusta
Synedra dilicatissima
Synedra delicatissima v. angustissima
Synedra filiformis
Synedra minuscula
Synedra ostenfeldii
Synedra rumpens
Synedra ulna
Synedra ulna v. claviceps
Synedra vaucheriae
Synedra vaucheriae v. capitata
Synedra vaucheriae v. capitellata
Synedra vaucheriae v. fragilariodes
Tabellaria fenestrata

Very common species

Amphipleura pellucida
Asterionella formosa
Diatoma tenue v. elongatum
Fragilaria genus-except those listed as rare
Melosira granulata
Nitzschia genus-except those listed as rare
Synedra genus-except those listed as rare
Tabellaria fenestrata

Rare species

Achnanthes clevei v. rostrata
Achnanthes haukiana v. rostrata
Achnanthes lanceolata v. elliptica
Achnanthes linearis
Cocconeis placentula
Coscinodiscus subsalsa
Cyclotella ocellata
Cyclotella pseudostelligera
Diploneis parma
Epithemia sp.
Fragilaria brevistriata v. inflata
Fragilaria construens v. binodis
Fragilaria leptostauron
Fragilaria pantocsekii v. binodis
Fragilaria parasitica
Fragilaria vaucheriae v. truncata
Gyrosigma spencerii v. curvala
Meridion circulare
Navicula gastrum v. signata
Navicula grimmei
Navicula integra
Navicula nyassensis f. minor
Navicula platystoma v. pantoscekii
Navicula reinhardtii
Navicula similis
Navicula tuscula f. rostrata
Neidium dubium
Nitzschia hungarica
Nitzschia insecta
Nitzschia Kutzingiana
Nitzschia macilenta
Nitzschia vexans
Nitzschia sp. 1
Nitzschia sp. 2

Table 17 con't. Sample N15B, August 1972

Achnanthes affinis
Achnanthes clevei
Achnanthes clevei v. rostrata
Achnanthes lanceolata
Achnanthes lanceolata v. dubia
Achnanthes lapponica
Achnanthes minutissima
Amphipleura pellucida
Amphora calumetica
Amphora cruciferoides
Amphora montana
Amphora normani
Amphora ovalis
Amphora ovalis v. libyca
Amphora ovalis v. pediculus
Asterionella formosa
Caloneis bacillum
Cocconeis diminuta
Cocconeis pediculus
Cocconeis placentula
Cyclotella comta
Cyclotella cryptica
Cyclotella Kutzingiana
Cyclotella meneghiniana
Cyclotella meneghiniana v. plana
Cyclotella michiganiana
Cyclotella ocellata
Cyclotella pseudostelligera
Cyclotella stelligera
Cymatopleura solea v. apiculata
Cymbella microcephala
Cymbella parvula
Cymbella prostrata
Cymbella subventricosa
Diatoma tenue v. elongatum
Diatoma vulgare
Diploneis parma
Eunotia arcus
Fragilaria capucina
Fragilaria construens
Fragilaria construens v. binodis
Fragilaria crotonensis
Fragilaria intermedia
Fragilaria leptostauron
Fragilaria pinnata
Fragilaria pinnata v. lancettula
Fragilaria vaucheriae v. fragilariodes
Fragilaria vaucheriae v. lanceolata
Fragilaria vaucheriae v. truncata
Gomphonema clevei
Gomphonema intricatum
Gomphonema intricatum v. pumila
Gomphonema olivaceum
Gyrosigma spencerii
Melosira granulata
Melosira islandica
Melosira italica
Meridion circulare
Navicula aurora
Navicula anglica v. subsalsa
Navicula capitata
Navicula capitata v. hungarica
Navicula capitata v. luneburgensis
Navicula cryptocephala
Navicula cryptocephala v. intermedia
Navicula decussis
Navicula gastrum
Navicula gregaria
Navicula integra
Navicula latens
Navicula menisculus v. obtusa
Navicula menisculus v. upsaliensis
Navicula micropupula
Navicula nyassensis f. minor
Navicula platystoma v. pantoscekii
Navicula protracta
Navicula pupula
Navicula pupula v. rostrata
Navicula radiosa v. tenella
Navicula simplex
Navicula seminuloides
Navicula seminulum
Navicula tripunktata
Navicula tuscula v. minor
Navicula viridula
Navicula sp. (our #40)
Navicula sp. (our #78)
Neidium dubium
Nitzschia acicularis
Nitzschia acuta
Nitzschia amphibia
Nitzschia angustata v. acuta
Nitzschia bacata
Nitzschia capitellata
Nitzschia confinis
Nitzschia dissipata
Nitzschia fonticola
Nitzschia insecta
Nitzschia macilenta
Nitzschia palea
Nitzschia recta
Nitzschia romana

Table 17 con't. Sample N15B, August 1972 con't.

Nitzschia spiculoides
Nitzschia sublinearis
Nitzschia tryblionella
Nitzschia sp. (our #1)
Nitzschia sp. (our #2)
Nitzschia sp. (our #8)
Oestrupia zachariasi v. undulata
Rhoicosphenia curvata
Stauroneis acutiuscula
Stephanodiscus alpinus
Stephanodiscus astraea
Stephanodiscus hantzschii
Stephanodiscus minutus
Stephanodiscus niagarae
Stephanodiscus subtilis
Stephanodiscus tenuis
Surirella angusta
Surirella ovata
Synedra demerarae
Synedra delicatissima
Synedra filiformis
Synedra minuscula
Synedra parasitica
Synedra parasitica v. subconstricta
Synedra ulna
Synedra vaucheriae
Tabellaria fenestrata

Very common species

Asterionella formosa
Diatoma tenue v. elongatum
Melosira granulata
Tabellaria fenestrata

Common species

Achnanthes minutissima
Amphipleura pellucida
Cyclotella meneghiniana v. plana
Cyclotella ocellata
Cyclotella stelligera
Cymbella microcephala
Fragilaria crotonensis
Fragilaria vaucheriae v. fragilariodes
Navicula cryptocephala
Navicula cryptocephala v. intermedia
Navicula decussis
Navicula latens
Navicula menisculus v. upsaliensis
Navicula micropupula
Navicula tripunktata
Navicula viridula
Nitzschia bacata
Nitzschia confinis
Nitzschia dissipata
Nitzschia fonticola
Nitzschia palea
Stephanodiscus genus
Synedra delicatissima
Synedra minuscula
Synedra ulna
Synedra vaucheriae

Rare species

Achnanthes lapponica
Amphora calumetica
Amphora cruciferoides
Amphora montana
Amphora mormani
Cocconeis diminuta
Cyclotella cryptica
Diatoma vulgare
Diploneis parma
Eunotia arcus
Gyrosigma spencerii
Navicula aurora
Navicula integra
Navicula platystoma v. pantoscekii
Navicula protracta
Navicula simplex
Navicula seminuloides
Navicula seminulum
Navicula tuscula v. minor
Navicula sp. (our #40)
Navicula sp. (our #78)
Nitzschia acicularis
Nitzschia amphibia
Nitzschia capitellata
Nitzschia macilenta
Nitzschia romana
Nitzschia sublinearis
Nitzschia tryblionella
Nitzschia sp. (our #8)
Oestrupia zacharasi v. undulata
Rhoicosphenia curvata
Stauroneis acutiuscula

Table 17 con't. Sample N15B, September 1972.

The two prepared slides were devoid of all materials.

Sample N15B, October 1972

Achnanthes affinis
Achnanthes clevei
Achnanthes lanceolata
Achnanthes lanceolata v. dubia
Achnanthes lanceolata v. elliptica
Achnanthes linearis
Achnanthes microcephala
Achnanthes minutissima
Achnanthes suchlandti
Amphipleura pellucida
Amphora normani
Amphora ovalis
Amphora ovalis v. libyca
Asterionella formosa
Caloneis bacillum
Caloneis ventricosa v. minuta
Cocconeis diminuta
Cocconeis placentula
Cyclotella comta
Cyclotella cryptica
Cyclotella Kutzingiana
Cyclotella meneghiniana v. plana
Cyclotella michiganiana
Cyclotella ocellata
Cyclotella pseudostelligera
Cyclotella stelligera
Cymbella delicatula
Cymbella microcephala
Cymbella prostrata
Diatoma tenue v. elongatum
Diatoma vulgare
Diploneis parma
Diploneis oculata
Fragilaria brevistriata
Fragilaria brevistriata v. inflata
Fragilaria construens
Fragilaria construens v. binodis
Fragilaria construens v. capitata
Fragilaria construens v. minuta
Fragilaria construens v. venter
Fragilaria crotonensis
Fragilaria intermedia
Fragilaria leptostauron
Fragilaria pantocsekii v. binodis
Fragilaria parasitica v. subconstricta
Fragilaria pinnata
Fragilaria pinnata v. lancettula
Fragilaria vaucheriae
Fragilaria vaucheriae v. fragilariodes
Gomphenema angustatum
Gomphenema angustatum v. producta
Gomphenema gracile
Gomphenema olivaceum
Gomphenema parvulum
Gomphenema subclavatum
Gomphenema sp.
Gyrosigma spencerii v. curvula
Melosira granulata
Melosira islandica
Melosira italica
Navicula anglica v. signata
Navicula bacillum
Navicula capitata v. luneburgensis
Navicula costulata
Navicula cryptocephala
Navicula cryptocephala v. intermedia
Naveula decussis
Navicula gregaria
Navicula latens
Navicula menisculus v. upsaliensis
Navicula micropupula
Navicula mutica v. cohnii
Navicula nyassensis f. minor
Navicula protracta
Navicula pupula
Navicula tuscula
Navicula viridula
Navicula sp. (our #78)
Neidium dubium
Neidium sp. (our #4)
Nitzschia amphibia
Nitzschia angusta v. acuta
Nitzschia bacata
Nitzschia confinis

Table 17 con't. Sample N15B, October 1972 con't.

Nitzschia dissipata
Nitzschia fonticola
Nitzschia insecta
Nitzschia palea
Nitzschia recta
Nitzschia romana
Nitzschia tryblionella
Nitzschia woltereckii
Nitzschia sp. (our #1)
Nitzschia sp. (our #2)
Nitzschia sp. (our #8)
Nitzschia sp.
Oestrupia zachariasi v. undulata
Rhoicosphenia curvata
Stephanodiscus alpinus
Stephanodiscus astraea
Stephanodiscus hantzschii
Stephanodiscus minutus
Stephanodiscus niagarae
Stephanodiscus subtilis
Stephanodiscus tenuis
Stephanodiscus transilvanicus
Surirella angusta
Surirella ovata
Synedra acus
Synedra amphicephala
Synedra amphicephala v. austraica
Synedra delicatissima
Synedra delicatissima v. angustissima
Synedra filiformis
Synedra hyperborea v. rostellata
Synedra minuscula
Synedra montana
Synedra ostenfeldii
Synedra pulshella
Synedra rumpens v. meneghiniana
Synedra tenera
Synedra ulna
Synedra ulna v. chaseana
Synedra ulna v. claviceps
Synedra vaucheriae v. capitellata
Tabellaria fenestrata

Common species

Achnanthes minutissima
Asterionella formosa
Cyclotella comta
Cyclotella meneghiniana v. plana
Cyclotella ocellata
Cyclotella stelligera
Diatoma tenue v. elongatum
Fragilaria construens
Fragilaria vaucheriae
Melosira granulata
Navicula cryptocephala
Navicula cryptocephala v. intermedia
Nitzschia dissipata
Nitzschia fonticola
Nitzschia palea
Stephanodiscus astraea
Stephanodiscus hantzschii
Stephanodiscus minutus
Synedra acus
Synedra amphicephala v. austiaica
Synedra delicatissima
Synedra tenera
Synedra ulna (all varieties)
Synedra vaucheriae v. capitellata
Tabellaria fenestrata

Rare species

Achnanthes clevei
Achnanthes linearis
Achnanthes suchlandti
Amphipleura pellucida
Amphora genus
Caloneis genus
Cocconeis genus
Cyclotella cryptica
Diatoma vulgare
Diploneis genus
Gomphonema sp.
Gyrosigma spencerii v. curvula
Navicula anglica v. signata
Navicula bacillum
Navicula mutica v. cohnii
Navicula tuscula
Neidium genus
Nitzschia tryblionella
Nitzschia woltereckii
Nitzschia sp.
Oestrupia zachariasi v. undulata
Rhoicosphenia curvata
Synedra hyperborea v. rostellata
Synedra montana
Synedra pulshella

A.5 *Study of Zooplankton*

James C. Roth

Distribution of Samples in Space and Time

We report here the results of the 1972 zooplankton collections. The data were collected at 140 stations in the Cook Plant survey area, distributed as follows:

Date, 1972		Number of Stations: Counted to Species	Counted to Genus	Total
12 April	(full survey, old grid)	5	41	46
4 May	(short survey)	3	5	8
11 June	(short survey)	3	5	8
16 July	(full survey, reduced grid)	5	24	29
11 August	(short survey)	3	4	7
8 September	(short survey)	3	4	7
15 October	(full survey, reduced grid)	5	23	28
3 November	(short survey)	3	4	7
		30	110	140

The positions of the stations are shown in Figures 5 through 7. Samples were enumerated to the species level at five stations (DC-6, DC-5, DC-2; NDC-7-1; SDC-7-1) in each of the full surveys (April, July, and October), and at three stations (DC-6, DC-5, DC-2) in each of the short monthly surveys. The balance of the samples were enumerated to the genus level. After July 1972 station DC-1 could not be sampled because dredges installing the plant intake structures were anchored there.

Methods

Because changes have been instituted in zooplankton methods since the last report, the present methods will be described in some detail. The differences are primarily in laboratory handling and enumeration, and, although they are more time-consuming, we believe they are also more accurate.

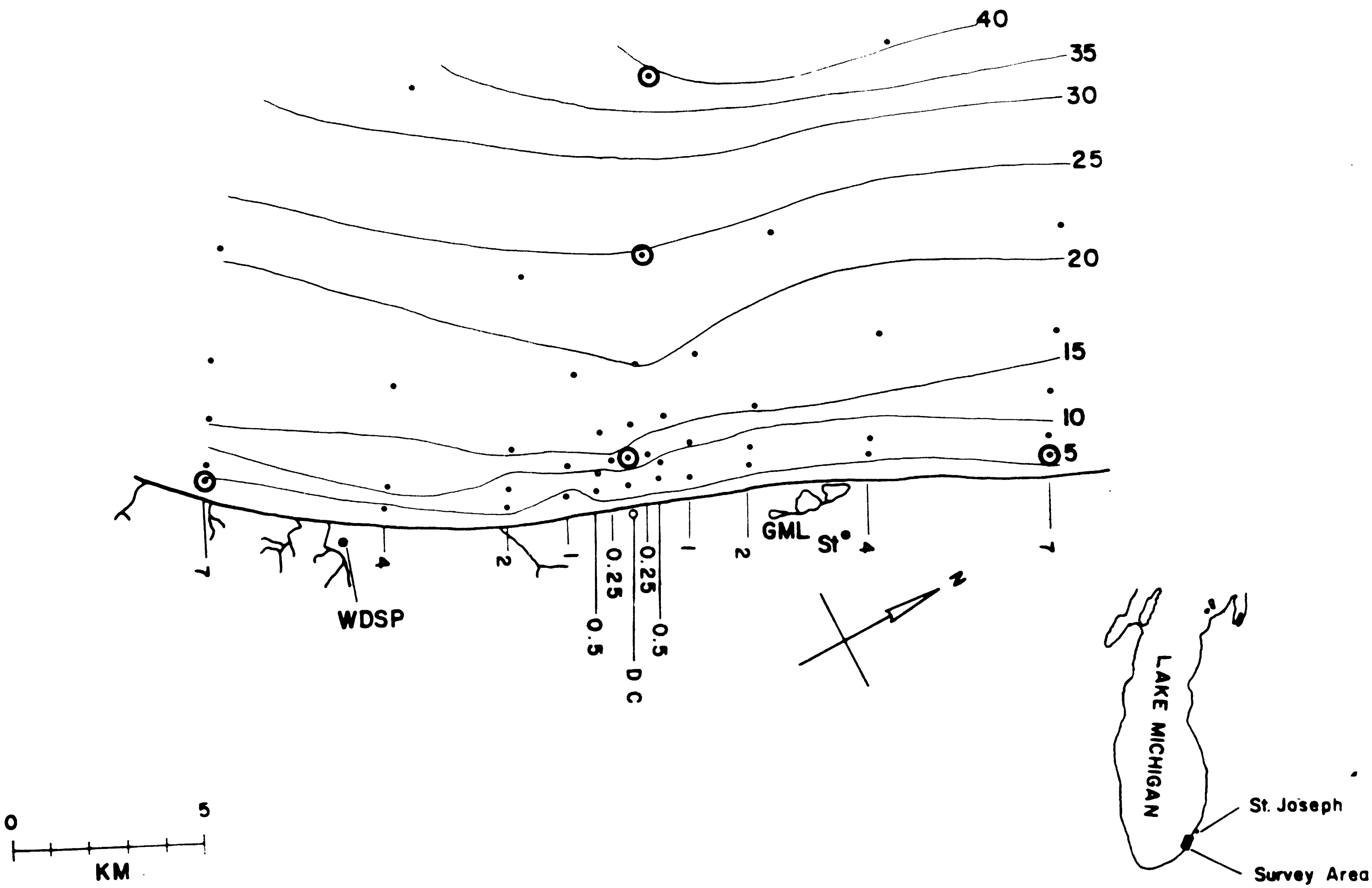

Figure 5. Zooplankton stations sampled on 12 April 1972. Samples from the 5 circled stations were enumerated to species and those from the other 41 stations were enumerated to genus.

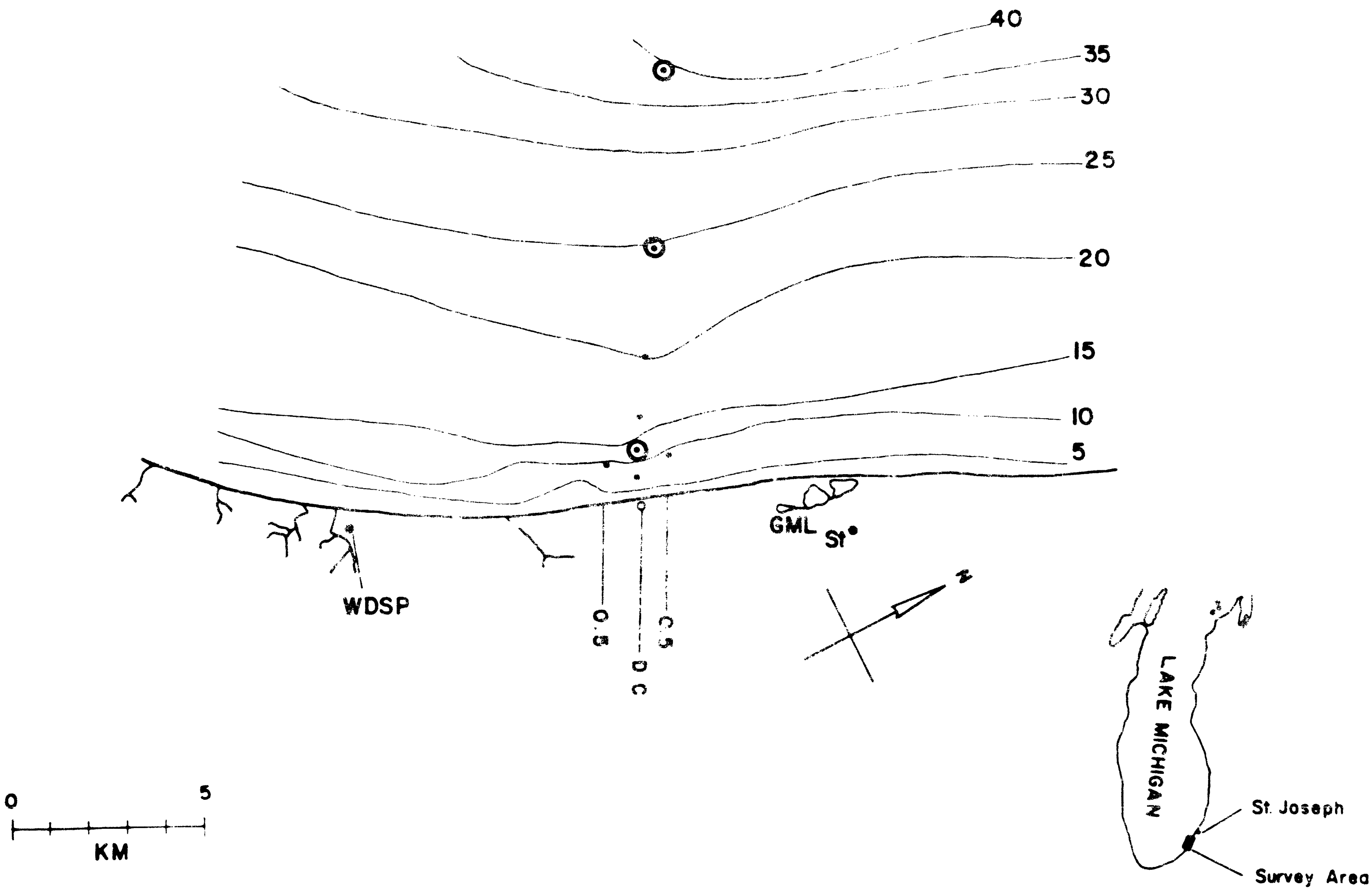

Figure 6. Zooplankton stations sampled on 4 May, 11 June, 11 August, 8 September, and 3 November 1972. Samples from the 3 circled stations were enumerated to species and those from the other 5 stations were enumerated to genus. Station DC-1 was not sampled on the last 3 dates.

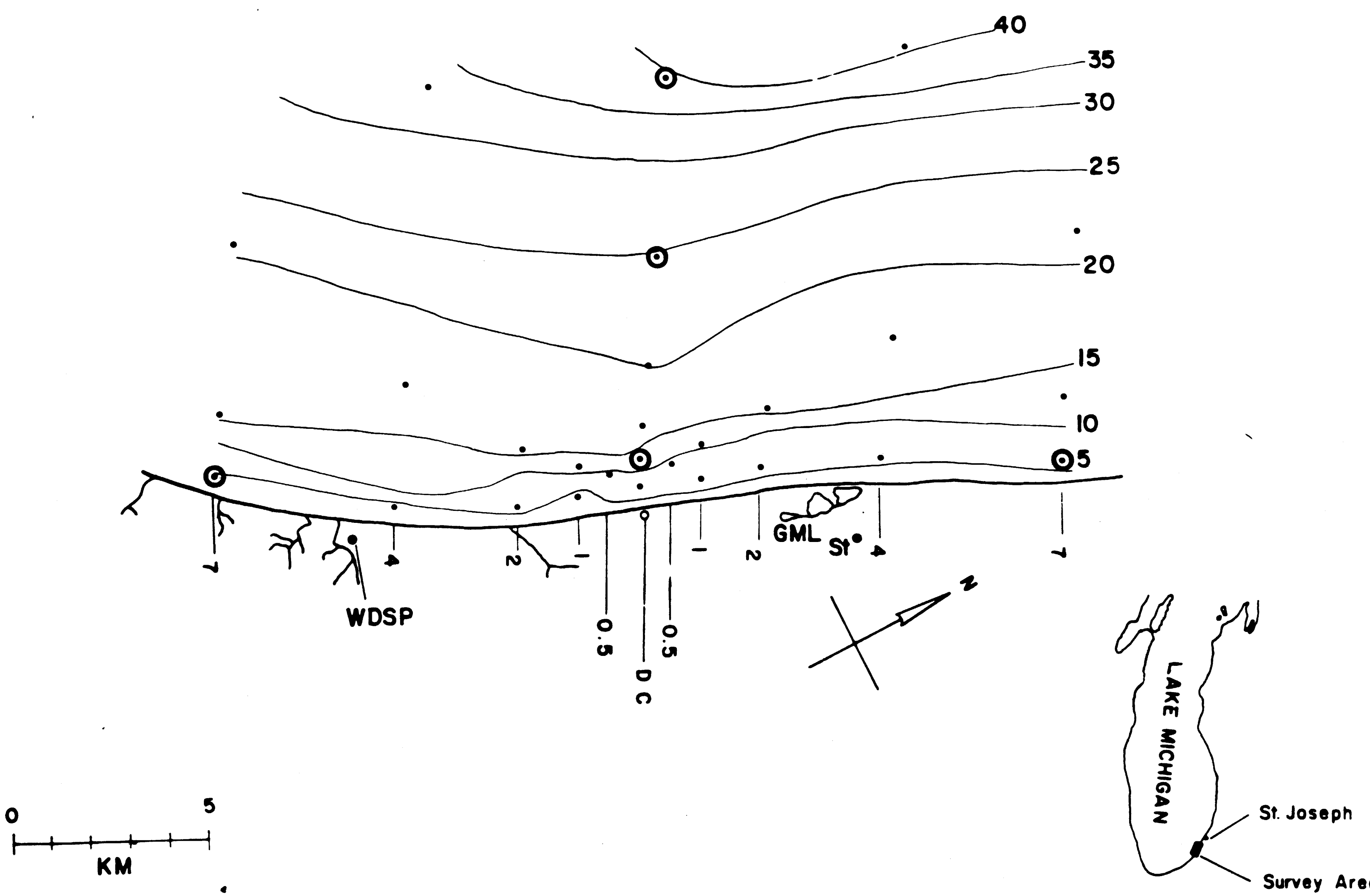

Figure 7. Zooplankton stations sampled on 16 July and 15 October 1972. Samples from the 5 circled stations were enumerated to species and those from the other 24 stations were enumerated to genus. Station DC-1 was not sampled in October.

At each station, a vertical haul from the bottom to the surface was made with a 1/2 meter cone net of #10 nylon mesh (158 μ apertures). This mesh size retains all adult cladocerans and copepods (including small species such as *Tropocyclops prasinus*), but probably does not quantitatively recover small nauplii or small rotifers. A flowmeter placed in the mouth of the net estimated the volume of water filtered. About 1 - 10 m^3 of water were filtered, depending on the length of the tow. A small amount of carbon dioxide (sparkling water, club soda) was added to each sample before preservation to relax the animals; then they were preserved with Koechie's Fluid (a mixture of 750 ml saturated sugar solution, 300 ml concentrated formalin, and 2850 ml distilled water), which was used rather than formalin to further minimize distortion of the microcrustacea, in particular "ballooning" of cladoceran carapaces.

The samples were too large to count in their entirety, so they were subsampled in the laboratory with a Folsom plankton splitter. Splitters of this type provide more satisfactory subsamples than pipettes (Cassie, 1971). Each sample was split as many times as was needed to yield a subsample of manageable size which still permits statistical reliability. At each split the half which was used for further splits or for counting was chosen at random (by tossing a coin). Duplicate subsamples for counting were selected, each of which contained several hundred of the most common forms. The quantitative and qualitative objectives of the enumeration method, and the extent to which they were realized, are discussed later. Subsamples were counted in a chamber of original design which combines the features of Gannon's chambered cell (Gannon, 1971) and Ward's plankton wheel (Ward, 1955). Stereozoom microscopes capable of magnifications up to 210X were used; these combined with the open top feature of the chamber (permitting manipulation of specimens into favorable viewing positions) made it possible to identify species of microcrustacea without dissection.

Total zooplankton weights were determined from the counted splits. In some cases, the samples contained so much algae that realistic "zooplankton" weights could not be determined. These samples were not weighed. The balance of the samples yielded what we consider to be crude but reliable estimates of the zooplankton biomass. Although our #10 net probably underestimated the numbers of very small forms (rotifers, small nauplii), this error may have been partly offset by the inclusion of some net phytoplankton. We weighed zooplankton on No. 1 Whatman filter papers, 5 cm in diameter, using a Mettler H54 electrobalance (least division = 0.1 mg; estimates to 0.01 mg). Before weighing, the filters were dried in an oven at ca. 100C for at least four hours. Several procedures were tried to minimize errors due to absorption of moisture by the filters, and the following treatment proved to be simple and precise. Filters were taken from the oven and placed on the balance. The weight was recorded one minute after removal from the oven. Re-weighings of filters after mock treatments (filtering 100 ml tap water and then re-drying) provided an estimate of the precision of this method. Ten filters showed a weight change ranging from -0.06 mg to +0.25 mg(mean: +0.06; s.d.: 0.1). The zooplankton samples usually weighed between 2 and 16 mg, so that at the most, these errors ammounted to between 1 and 12% of the sample weight; other sources of error in the methods are greater than this. However, a couple of zooplankton samples weighed only ca. 0.5 mg, so in these cases the weighing error could at worst approach half of the sample weight.

It is appropriate to include a few remarks on the statistical problems of zooplankton sampling and enumeration. Workers who have taken repeated zooplankton samples from the same station have found that the coefficient of variation (the standard deviation expressed as a percentage of the mean) is around 25% (Nauwerck, 1963) or more, sometimes considerably more. It is therefore of interest to consider how to divide the available effort between the extremes of

taking many small samples or a few large ones. The choice is made a little easier by the problems of enumeration in the laboratory. Even a relatively small sample (say, 10 liters) may contain far too many individuals (1,000 - 2,000) to count them all; so the field sample must be quantitatively subsampled. In theory, the subsample is considerably less variable than the field sample. It is therefore reasonable strategy to take large samples which integrate over sizeable areas of vertical and/or horizontal patchiness, and subsample these for counting. Another consideration is how large a subsample to count. Here it depends partly upon the questions being asked. If only quantitative information is sought, about 50 individuals may suffice (Ricker, 1938; Cassie, 1971). However, in many studies -- including this one -- it is of perhaps equal interest to get qualitative data on the occurrence of rare species, in order to document the early appearance or disappearance of diagnostic or noxious species. Counting only 50 individuals will not reveal the rare species. We adopted the strategy to take large field samples (several cubic meters) and enumerate rather large subsamples from them. For this purpose we designed a new counting chamber which accepts a subsample of around 10 ml. For the 1972 data we enumerated duplicate subsamples in order to test whether our subsampling scheme was effective. Some species are too rare to get meaningful quantitative information about them; our data show that if an animal comprises less than 5% of the total, our counts must be considered qualitative only, even though the total number of animals enumerated approaches 1,000. Figure 8 illustrates this; the coefficients of variation between duplicate subsamples (species counts) are plotted against the relative abundance of the species, for all species which accounted for more than 5% of the fauna. The line encloses 95% of the points, and it is apparent that if an organism comprises 15% or more of the total fauna, the coefficient of variation will be 15% or less. The coefficient of variation decreases with increasing commonness of the species;

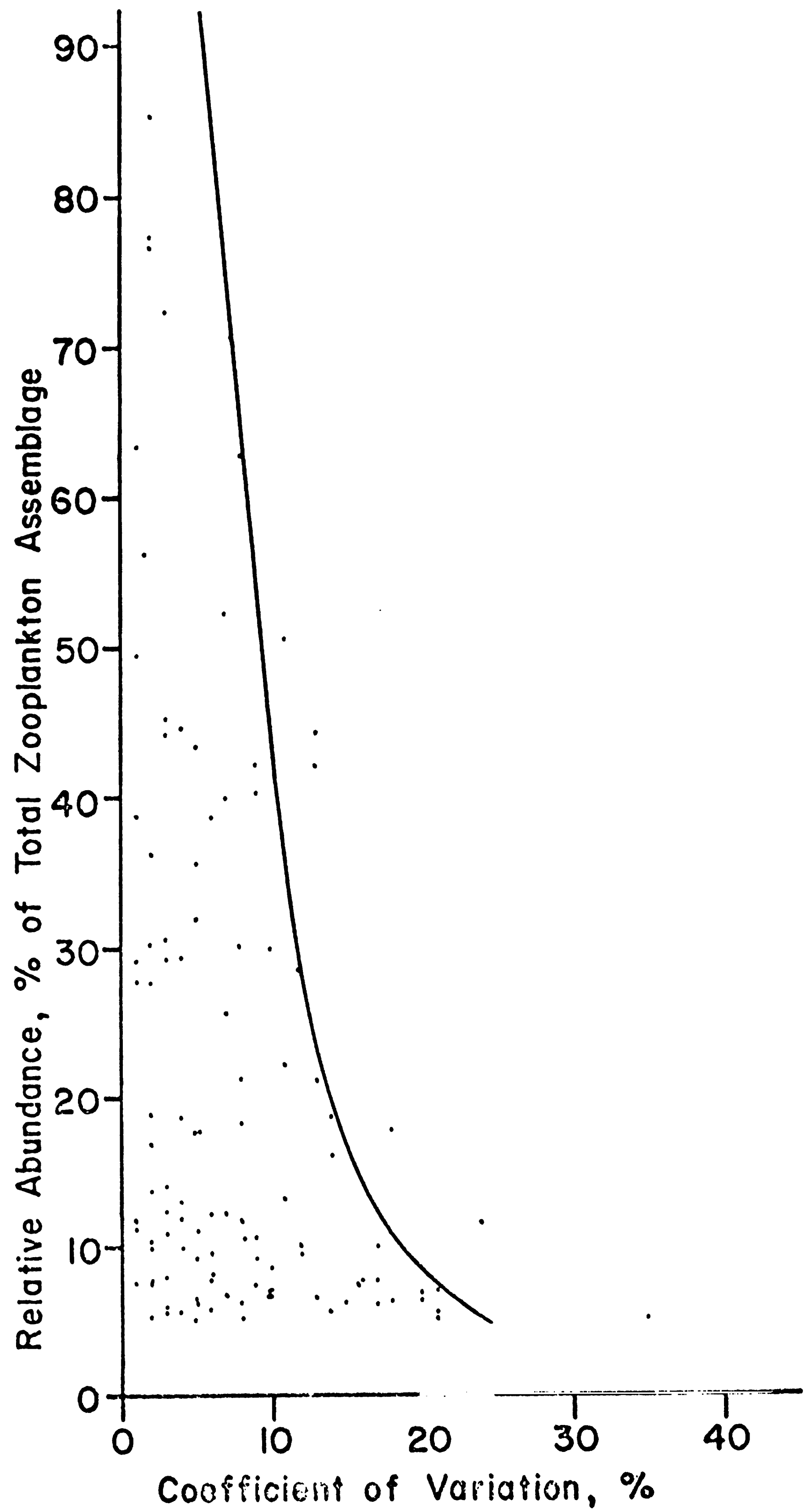

Figure 8. The coefficient of variation (%) between duplicate zooplankton subsamples plotted against the relative abundance (% of total zooplankton assemblage) for 110 species counts which amounted to over 5% of the total zooplankton assemblage. The line is drawn by eye to enclose 95% of the points.

animals that make up 45% or more of the assemblage -- dominant species -- are counted to within 5 - 10%. These figures are encouraging, since they are less than the expected field sampling error. It is worth considering, for subsequent surveys, to replicate samples in the field, and count only one subsample from each tow. However, the genus counts show considerably more variability between subsamples, approaching the variability expected between replicated samples. This problem must be worked out before counting duplicate subsamples is abandoned. The genus counts were made by a different enumerator than the species counts. Some sources of error may be counting too small subsamples, and/or insufficient care taken with the splitter. Longhurst and Seibert (1967) have shown that the Folsom splitter gives its most satisfactory results when the operator is skilled.

Qualitative Results

The 21 zooplankton Crustacea species which made up the 1972 fauna in the study area are shown in Table 18, along with the maximum percentage of the total fauna that each attained during the study period. Three cyclopoid copepods were found; only one (*Cyclops bicuspidatus thomasi*) can be considered among the dominants. *Cyclops vernalis* never exceeded 1% of the total, and *Tropocyclops prasinus mexicanus* never more than 3%.

Calanoid copepods comprised 7 species, four of them in the genus *Diaptomus*. *Diaptomus ashlandi* was the most common of the *Diaptomus* species, and was a major offshore species in spring. *Diaptomus minutus* at times made up 12% of the assemblage, but the other two diaptomids (*D. oregonensis* and *D. sicilis*) were less common. Three other calanoids, *Eurytemora affinis*, *Epischura lacustris*, and *Limnocalanus macrurus*, were never common; the former is an introduced brackish water species, and the latter is a glacial relic.

Table 18. The 1972 zooplankton Crustacea (16 Genera, 21 Species)

	Max. % of fauna attained in 1972 collections
Cyclopoid copepods (2 genera, 3 species)	
Cyclops bicuspidatus thomasi S. A. Forbes	42
Cyclops vernalis Fischer	<1
Tropocyclops prasinus mexicanus Kiefer	3
Calanoid copepods (4 genera, 7 species)	
Diaptomus ashlandi Marsh	43
Diaptomus minutus Lilljeborg	12
Diaptomus oregonensis Lilljeborg	9
Diaptomus sicilis S. A. Forbes	2
Epischura lacustris S. A. Forbes	1
Eurytemora affinis (Poppe)	<1
Limnocalanus macrurus Sars	1
Harpacticoid copepods (1 genus, 1 species)	
Canthocamptus sp.	1
Cladocerans (9 genera, 10 species)	
Bosmina longirostris (O. F. Müller)	85
Ceriodaphnia quadrangula (O. F. Müller)	<1
Chydorus sphaericus (O. F. Müller)	<1
Daphnia galeata mendotae Birge	6
Daphnia retrocurva S. A. Forbes	16
Diaphanosoma leuchtenbergianum Fischer	1
Eubosmina coregoni (Baird)	12
Holopedium gibberum Zaddach	7
Leptodora kindtii (Focke)	<1
Polyphemus pediculus (Linné)	1

One harpacticoid copepod, *Canthocamptus* sp. (perhaps *C. robertcokeri* M. S. Wilson, but this must be verified) occurred sporadically.

The cladoceran fauna was rich, especially in summer. *Bosmina longirostris* was the most common cladoceran and the most common zooplankter in summer, making up as much as 85% of the fauna. Another bosminid, *Eubosmina coregoni* was less common, but sometimes made up over 10% of the total. *Daphnia retrocurva* was the only other cladoceran common enough to account for over 10%. The other 7 cladocerans were *Daphnia galeata mendotae*, *Holopedium gibberum*, *Polyphemus pediculus*, *Diaphanosoma pediculus*, *Diaphanosoma leuchtenbergianum*, *Ceriodaphnia quadrangula*, *Chydorus sphaericus*, and *Leptodora kindtii*, in order of decreasing abundance.

Several genera of rotifers were found in summer. However, only one species (*Asplanchna* sp., probably *Asplanchna priodonta* Gosse) was enumerated. The others are too small to be collected by our nets, and require special handling to identify.

Several other species were found only occasionally, and are listed in Table 19. Usually a single individual was found in a collection; the number of occurrences of each species is listed. Three rare cyclopoids were noted. Two are littoral-benthic forms (*Eucyclops agilis* and *Paracyclops fimbriatus poppei*) and may be expected to occur accidentally in nearshore collections. The third species, *Mesocyclops edax*, is a large cyclopoid which was once much more common in Lake Michigan. Its decline was attributed by Wells (1970) to size-selective alewife predation.

One calanoid species, *Diaptomus reighardi*, occurred only once; this record is very interesting because this species has not been reported from Lake Michigan before (Robertson, 1966); it is known from Lake Erie. Whether this specimen is an accidental individual washed out from an inland lake, or whether a breeding population is developing in Lake Michigan, will be watched with great

Table 19. Rare zooplankton species, 1972. Occurrences at our 30 species and 110 genera stations.

	Occurences at: Species Stas.	Genera Stas.
Cyclopoid copepods		
Eucyclops agilis (Koch)	1	
Mesocyclops edax (S. A. Forbes)	1	
Paracyclops fimbriatus poppei (Rehberg)		1
Calanoid copepods		
Diaptomus reighardi Marsh	1	
Cladocerans		
Alona spp.	4	2
Alonella sp.	1	
Daphnia longiremus Sars	4	
Eurycercus lamellatus (O. F. Müller)		5
Ilyocryptus sordidus (Liéven)	1	
Leydigia quadrangularis (Leydig)	1	1
Macrothrix laticornis (Jurine)	1	5
Pleuroxus denticulatus Birge		1
Acarina	1	
Amphipoda		
Pontoporeia affinis Lindstrom	2	1
Mysidacea		
Mysis relicta Lovén		1

interest in subsequent surveys. Another calanoid, *Senecella calanoides* Juday, is known from Lake Michigan, but did not occur in our samples. It is a deep-water species and not common now (Gannon, 1972).

Seven species of macrothricid and chydorid Cladocera were found, all of which are littoral-benthic in habitat, and are only occasionally a part of the true plankton. One species, *Daphnia longiremus*, is a true plankter associated with cold, deep waters in Lake Michigan. We noted it in small numbers only four times. (Entrainment studies we conducted in February 1973 suggest that this species may be relatively more common in our zone in winter, although it is not numerous then.)

The occurrence of *Pontoporeia* and *Mysis* in a few samples is not noteworthy; these benthic Crustacea occasionally wander some distance above the sediments.

The dominant species then, were *Cyclops bicuspidatus thomasi*, *Diaptomus ashlandi*, *D. minutus*, *Bosmina logirostris*, *Daphnia retrocurva*, and *Eubosmina coregoni*. It may be said that the qualitative composition of the 1972 Lake Michigan fauna in our area was comparable to that reported in other recent studies (Gannon, 1972; Wells, 1970). The astonishing quantitative development of *Bosmina longirostris* is discussed in the following section.

Quantitative Results

The primary data are given in Tables 20 through 27 (species counts) and 28 through 35 (generic counts); included for each station are the mean number of each taxon (individuals/m^3), the coefficient of variation (i.e., the standard deviation expressed as a percentage of the mean) between duplicate subsamples, the percent composition of the fauna, the dry weight (milligrams/m^3), and the mean zooplankter weight (micrograms/individual). In the pages that follow, the 1972 data are presented in a fairly detailed though non-rigorous way. In subsequent

Table 20. Zooplankton species counts (ind/m^3), coefficients of variation between duplicate subsamples, percent composition by species, total zooplankton weight (mg/m^3), and mean zooplankter weight (μg/ind) for 5 stations sampled on 12 April 1972.

Species	DC-6			DC-5			DC-2			NDC-7-1			SDC-7-1		
	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%
Copepod nauplii	472	9	10.1	1,521	1	28.6	1,920		23.2	1,653	7	53.7	569		45.2
Cyclopoid copepods															
Immature copepodids	291	20	6.2	418	6	7.9	853		10.3	562	5	18.3	219		17.4
Cyclops bicuspidatus thomasi	1,270	12	27.2	1,689	5	31.8	3,487		42.2	349	3	11.3	102		8.1
Cyclops vernalis				14	143	0.3									
Tropocyclops prasinus mexicanus	10	141	0.2	27	0	0.5	27		0.3	13	47	0.4	2		0.2
Calanoid copepods															
Immature copepodids	281	15	6.0	191	27	3.6	213		2.6	64	44	2.1	79		6.3
Diaptomus ashlandi	1,933	5	41.5	990	14	18.6	1,240		15.0	247	16	8.0	183		14.5
Diaptomus minutus	136	37	2.9	191	14	3.6	180		2.2	38	25	1.2	44		3.5
Diaptomus oregonensis	60	47	1.3	91	43	1.7	133		1.6	13	95	0.4			
Diaptomus sicilis	100	57	2.1	95	34	1.8	53		0.6				23		1.8
Epischura lacustris															
Eurytemora affinis															
Limnocalanus macrurus	60	23	1.3	73	35	1.4	60		0.7	38	25	1.2	6		0.5
Harpacticoid copepods															
Canthocamptus sp.				9	139	0.2	33		0.4	47	7	1.5	17		1.4
Cladocerans															
Bosmina longirostris	40	70	0.9	9	0	0.2	20		0.2	11	0	0.4	6		0.5
Ceriodaphnia quadrangula										2	142	0.1			
Chydorus sphaericus							13		0.2	29	33	0.9	8		0.6
Daphnia galeata mendotae										4	0	0.1			
Daphnia retrocurva															
Diaphanosoma leuchtenbergianum															
Eubosmina coregoni															
Holopedium gibberum															
Leptodora kindtii															
Polyphemus pediculus															
Rotifers															
Asplanchna sp.							7		0.1						
TOTAL	4,663			5,318			8,259			3,079			1,258		
mg/m^3	41.1	7													
μg/individual	8.9	18													

Table 21. Zooplankton species counts (ind/m^3), coefficients of variation between duplicate subsamples, percent composition by species, total zooplankton weight (mg/m^3), and mean zooplankter weight (μg/ind) for 3 stations sampled on 4 May 1972.

Species	DC-4			DC-5			DC-2		
	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%
Copepod nauplii	528	12	9.5	2,533		41.5	3,904	2	77.2
Cyclopoid copepods									
Immature copepodids	247	25	4.4	66		1.1	267	35	5.3
Cyclops bicuspidatus thomasi	1,542	1	27.8	1,348		22.1	24	72	0.5
Cyclops vernalis									
Tropocyclops prasinus mexicanus	10	0	0.2						
Calanoid copepods									
Immature copepodids	334	3	6.0	353		5.8	507	12	10.0
Diaptomus ashlandi	1,619	3	29.2	1,328		21.7	136	4	2.7
Diaptomus minutus	645	24	11.6	209		3.4	94	43	1.9
Diaptomus oregonensis	480	10	8.6	68		1.1	15	58	0.3
Diaptomus sicilis	141	14	2.5	40		0.7	7	145	0.1
Epischura lacustris									
Eurytemora affinis									
Limnocalanus macrurus	5	0	0.1	18		0.3			
Harpacticoid copepods									
Canthocamptus sp.							4	0	0.1
Cladocerans									
Bosmina longirostris	10	0	0.2	46		0.8	26	71	0.5
Ceriodaphnia quadrangula									
Chydorus sphaericus				7		0.1	15	21	0.3
Daphnia galeata mendotae				40		0.7	9	72	0.2
Daphnia retrocurva									
Diaphanosoma leuchtenbergianum									
Eubosmina coregoni				15		0.2	2	145	0.0
Holopedium gibberum							2	145	0.0
Leptodora kindtii									
Polyphemus pediculus							2	145	0.0
Rotifers									
Asplanchna sp.				31		0.5	42	37	0.8
TOTAL	5,561			6,106			5,056		
mg/m^3	55.8	6	-	-	-	-	-	-	-
μg/individual	10.0	4	-	-	-	-	-	-	-

Table 22. Zooplankton species counts (ind/m^3), coefficients of variation between duplicate subsamples, percent composition by species, total zooplankton weight (mg/m^3), and mean zooplankter weight (μg/ind) for 3 stations sampled on 11 June 1972.

Species	DC-6 #/m^3	DC-6 cv	DC-6 %	DC-5 #/m^3	DC-5 cv	DC-5 %	DC-2 #/m^3	DC-2 cv	DC-2 %
Copepod nauplii	3,047	3	12.2	2,862	17	10.1	1,098	7	3.3
Cyclopoid copepods									
Immature copepodids	6,369	7	25.6	3,449	6	12.2	3,221	6	9.6
Cyclops bicuspidatus thomasi	914	7	3.7	71	34	0.3			
Cyclops vernalis	236	13	0.9				10	136	0.0
Tropocyclops prasinus mexicanus	23	44	0.1	27	0	0.1			
Calanoid copepods									
Immature copepodids	5,242	13	21.0	3,698	11	13.1	669	18	2.0
Diaptomus ashlandi	503	34	2.0	240	16	0.9			
Diaptomus minutus	130	8	0.5	373	44	1.3	31	55	0.1
Diaptomus oregonensis									
Diaptomus sicilis									
Epischura lacustris									
Eurytemora affinis	8	186	0.0				10	136	0.0
Limnocalanus macrurus									
Harpacticoid copepods									
Canthocamptus sp.	267	29	1.1	13	48	0.0	94	15	0.3
Cladocerans									
Bosmina longirostris	7,589	3	30.5	15,822	2	56.1	24,199	3	72.2
Ceriodaphnia quadrangula				8	147	0.0			
Chydorus sphaericus				8	147	0.0	105	84	0.3
Daphnia galeata mendotae	15	0	0.1	31	101	0.1	31	146	0.1
Daphnia retrocurva	76	0	0.3	27	93	0.1			
Diaphanosoma leuchtenbergianum	8	186	0.0						
Eubosmina coregoni									
Holopedium gibberum				4	159	0.0			
Leptodora kindtii									
Polyphemus pediculus									
Rotifers									
Asplanchna sp.	472	18	1.9	1,582	21	5.6	4,058	0	12.1
TOTAL	24,915			28,219			33,536		
mg/m^3	165.6	1	-	68.3	4	-	70.4	11	-
μg/individual	6.6	2	-	2.4	0	-	1.9	-	-

Table 23. Zooplankton species counts (ind/m^3), coefficients of variation between duplicate subsamples, percent composition by species, total zooplankton weight (mg/m^3), and mean zooplankter weight (µg/ind) for 5 stations sampled on 16 July 1972.

	DC-6			DC-5			DC-2			NDC-7-1			SDC-7-1		
Species	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%
Copepod nauplii	35,708	2	27.7	12,622	5	9.2	13,905	4	13.5	2,194	16	3.8	3,409	1	7.6
Cyclopoid copepods															
Immature copepodids	11,777	9	9.1	24,356	5	17.7	4,267	23	4.1	731	29	1.3	881	30	2.0
Cyclops bicuspidatus thomasi	12,753	2	9.9	19,333	3	14.1	29	35	0.0	76	32	0.1	23	75	0.1
Cyclops vernalis	63	0	0.0	267	0	0.2							17	81	0.0
Tropocyclops prasinus mexicanus	16	142	0.0	133	141	0.1	467	9	0.5	183	47	0.3	157	37	0.4
Calanoid copepods															
Immature copepodids	10,297	3	8.0	16,756	7	12.2	7,657	9	7.4	1,615	3	2.8	1,693	29	3.8
Diaptomus ashlandi	3,968	8	3.1	9,778	21	7.1				15	147	0.0	6	175	0.0
Diaptomus minutus	457	6	0.4	1,822	52	1.3	76	0	0.1	15	147	0.0	41	25	0.1
Diaptomus oregonensis	94	46	0.1	267	94	0.2									
Diaptomus sicilis	47	42	0.0	178	141	0.1	10	182	0.0						
Epischura lacustris															
Eurytemora affinis	63	71	0.0	133	47	0.1	86	12	0.1				64	65	0.1
Limnocalanus macrurus	189	0	0.1	44	142	0.0									
Harpacticoid copepods															
Canthocamptus sp.	16	142	0.0												
Cladocerans															
Bosmina longirostris	51,515	7	40.0	46,000	5	33.5	71,486	0	69.3	48,762	2	85.4	34,342	2	76.6
Ceriodaphnia quadrangula	31	146	0.0	133	47	0.1	48	30	0.0	15	147	0.0			
Chydorus sphaericus							86	47	0.1	15	147	0.0	17	81	0.0
Daphnia galeata mendotae	126	71	0.1	267	47	0.2	48	30	0.0						
Daphnia retrocurva	693	0	0.5	3,467	14	2.5	143	10	0.1	61	141	0.1	46	0	0.1
Diaphanosoma leuchtenbergianum										30	143	0.1			
Eubosmina coregoni				89	0	0.1									
Holopedium gibberum				178	0	0.1	29	35	0.0				6	175	0.0
Leptodora kindtii							19	0	0.0	15	147	0.0	6	175	0.0
Polyphemus pediculus	63	71	0.0	178	0	0.1	295	5	0.3	808	19	1.4	533	37	1.2
Rotifers															
Asplanchna sp.	1,039	21	0.8	1,422	26	1.0	4,629	3	4.5	2,560	4	4.5	3,594	6	8.0
TOTAL	128,915			137,423			103,286			57,110			44,845		
mg/m^3	371.3	2		304.0	8		110.3	15		106.4	11		118.1	26	
µg/individual	2.9	3		2.2	0		1.0	14		1.9	12		2.7	24	

Table 24. Zooplankton species counts (ind/m^3), coefficients of variation between duplicate subsamples, percent composition by species, total zooplankton weight (mg/m^3), and mean zooplankter weight (μg/ind) for 3 stations sampled on 11 August 1972.

Species	DC-6			DC-5			DC-2		
	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%
Copepod nauplii	6,162	16	7.6	5,310	5	5.1	8,533	5	3.0
Cyclopoid copepods									
Immature copepodids	24,576	2	30.3	17,771	2	16.9	33,482	0	11.9
Cyclops bicuspidatus thomasi	6,342	17	7.8	2,912	10	2.8	434	47	0.2
Cyclops vernalis	18	136	0.0	54	0	0.1			
Tropocyclops prasinus mexicanus	72	142	0.1	379	61	0.4	940	11	0.3
Calanoid copepods									
Immature copepodids	9,575	8	11.8	11,134	8	10.6	18,513	13	6.6
Diaptomus ashlandi	1,994	19	2.5	948	8	0.9	36	141	0.0
Diaptomus minutus	808	9	1.0	1,747	12	1.7	2,965	0	1.1
Diaptomus oregonensis	144	35	0.2	163	47	0.2	36	141	0.0
Diaptomus sicilis	36	145	0.0						
Epischura lacustris	36	0	0.0	27	143	0.0			
Eurytemora affinis	180	0	0.2	108	35	0.1	651	31	0.2
Limnocalanus macrurus	90	27	0.1						
Harpacticoid copepods									
Canthocamptus sp.									
Cladocerans									
Bosmina longirostris	24,378	10	30.0	51,850	1	49.4	178,043	1	63.4
Ceriodaphnia quadrangula	18	136	0.0	81	49	0.1	579	0	0.2
Chydorus sphaericus				122	16	0.1	108	48	0.0
Daphnia galeata mendotae	269	28	0.3	433	18	0.4	362	28	0.1
Daphnia retrocurva	2,443	27	3.0	6,231	6	5.9	12,149	2	4.3
Diaphanosoma leuchtenbergianum				54	142	0.1	72	0	0.0
Eubosmina coregoni	36	145	0.0	271	42	0.3	181	29	0.1
Holopedium gibberum	395	64	0.5	948	12	0.9	1,446	7	0.5
Leptodora kindtii				81	49	0.1	72	142	0.0
Polyphemus pediculus	162	15	0.2	149	39	0.1	362	28	0.1
Rotifers									
Asplanchna sp.	3,413	22	4.2	4,077	5	3.9	21,840	2	7.8
TOTAL	81,146			104,864			280,804		
mg/m^3	129.9	14		116.1	30		278.5	3	
μg/individual	2.6	14		1.1	26		1.0	0	

Table 25. Zooplankton species counts (ind/m^3), coefficients of variation between duplicate subsamples, percent composition by species, total zooplankton weight (mg/m^3), and mean zooplankter weight (μg/ind) for 3 stations sampled on 8 September 1972.

	DC-6			DC-3			DC-2		
Species	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%
Copepod nauplii	2,374	0	5.4	2,234	16	4.2	9,846	2	18.9
Cyclopoid copepods									
Immature copepodids	9,275	8	21.3	9,775	4	18.6	2,855	21	5.5
Cyclops bicuspidatus thomasi	2,022	17	4.6	1,955	7	3.7	263	17	0.5
Cyclops vernalis	19	143	0.0						
Tropocyclops prasinus mexicanus	538	15	1.2	714	43	1.4	1,313	18	2.5
Calanoid copepods									
Immature copepodids	18,365	13	42.1	22,156	9	42.1	21,038	9	40.3
Diaptomus ashlandi	1,354	14	3.1	279	31	0.5	16	149	0.0
Diaptomus minutus	250	15	0.6	403	22	0.8	1,625	21	3.1
Diaptomus oregonensis	334	24	0.8	621	0	1.2	263	17	0.5
Diaptomus sicilis	19	0	0.0						
Epischura lacustris	46	22	0.1	15	144	0.0	16	149	0.0
Eurytemora affinis							16	149	0.0
Limnocalanus macrurus	28	144	0.1						
Harpacticoid copepods									
Canthocamptus sp.									
Cladocerans									
Bosmina longirostris	241	54	0.6	1,195	2	2.3	1,870	32	3.6
Ceriodaphnia quadrangula									
Chydorus sphaericus									
Daphnia galeata mendotae	2,374	2	5.4	1,707	54	3.2	919	40	1.8
Daphnia retrocurva	4,526	2	10.4	8,285	14	15.7	6,137	1	11.7
Diaphanosoma leuchtenbergianum	28	51	0.1	202	76	0.4	607	12	1.2
Eubosmina coregoni	427	7	1.0	977	34	1.9	345	20	0.7
Holopedium gibberum	1,150	9	2.6	1,660	17	3.2	3,528	7	6.8
Leptodora kindtii	130	81	0.3	76	26	0.1	33	0	0.1
Polyphemus pediculus	9	188	0.0				49	45	0.1
Rotifers									
Asplanchna sp.	83	46	0.2	357	43	0.7	1,493	1	2.9
TOTAL	43,630			52,642			52,233		
mg/m^3	99.8	6		99.9	22		134	15	
μg/individual	2.3	16		2.0	25		2.5	23	

Table 26. Zooplankton species counts (ind/m^3), coefficients of variation between duplicate subsamples, percent composition by species, total zooplankton weight (mg/m^3), and mean zooplankter weight (μg/ind) for 5 stations sampled on 15 October 1972.

Species	DC-6			DC-5			DC-2			NDC-7-1			SDC-7-1		
	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%
Copepod nauplii	2,452	8	6.2	2,107	3	3.8	4,370	8	5.4	2,676	5	6.4	1,914	16	1.9
Cyclopoid copepods															
Immature copepodids	11,819	8	30.0	12,221	11	22.1	8,981	5	11.1	5,745	2	13.8	6,118	17	6.2
Cyclops bicuspidatus thomasi	2,550	5	6.5	2,335	1	4.2	1,239	12	1.5	449	12	1.1	439	20	0.4
Cyclops vernalis				53	142	0.1	34	145	0.0	19	141	0.0			
Tropocyclops prasinus mexicanus	1,103	3	2.8	1,229	8	2.2	1,067	5	1.3	487	22	1.2	3,075	23	3.1
Calanoid copepods															
Immature copepodids	17,508	13	44.4	24,441	3	44.1	14,692	8	18.2	4,136	4	10.0	2,165	23	2.2
Diaptomus ashlandi	454	11	1.2	509	6	0.9	129	28	0.2				31	141	0.0
Diaptomus minutus	98	35	0.2	88	30	0.2	189	0	0.2	9	147	0.0	157	85	0.2
Diaptomus oregonensis	221	32	0.6	316	16	0.6	155	31	0.2	65	21	0.2	94	47	0.1
Diaptomus sicilis															
Epischura lacustris	37	144	0.1	211	47	0.4	17	0	0.0						
Eurytemora affinis							86	85	0.1	9	147	0.0			
Limnocalanus macrurus															
Harpacticoid copepods															
Canthocamptus sp.							9	164	0.0						
Cladocerans															
Bosmina longirostris	49	141	0.1	527	28	1.0	31,346	6	38.8	20,996	11	50.6	62,055	8	62.9
Ceriodaphnia quadrangula				18	139	0.0	17	0	0.0	19	0	0.0	31	141	0.0
Chydorus sphaericus	12	164	0.0	70	0	0.1	241	40	0.3	94	0	0.2	63	0	0.1
Daphnia galeata mendotae	1,177	6	3.0	3,108	3	5.6	2,959	13	3.7	262	61	0.6	2,008	9	2.0
Daphnia retrocurva	699	37	1.8	3,670	10	6.6	3,303	24	4.1	1,142	12	2.8	4,486	9	4.5
Diaphanosoma leuchtenbergianum	441	47	1.1	685	11	1.2	413	0	0.5	206	0	0.5	157	85	0.2
Eubosmina coregoni	196		0.5	2,212	13	4.0	8,946	1	11.1	4,922	4	11.9	10,039		10.2
Holopedium gibberum				456	11	0.8	2,202	2	2.7	112	71	0.3	5,490	4	5.6
Leptodora kindtii	37	54	0.1	18	139	0.0	52	0	0.1	56	0	0.1	188	0	0.2
Polyphemus pediculus															
Rotifers															
Asplanchna sp.	564	12	1.4	1,089	9	2.0	327	22	0.4	112	24	0.3	188	47	0.2
TOTAL	39,417			55,363			80,808			41,516			98,698		
mg/m^3	73	1		134.5	11		-	-		-	-		240.3	14	
μg/individual	1.8	0		2.4	12		-	-		-	-		2.5	8	

Table 27. Zooplankton species counts (ind/m^3), coefficients of variation between duplicate subsamples, percent composition by species, total zooplankton weight (mg/m^3), and mean zooplankter weight (μg/ind) for 3 stations sampled on 3 November 1972.

Species	DC-6			DC-5			DC-2		
	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%
Copepod nauplii	1,195	3	4.1	1,138	42	3.5	1,110	18	4.1
Cyclopoid copepods									
Immature copepodids	13,300	3	45.3	9,500	4	29.3	12,019	4	44.6
Cyclops bicuspidatus thomasi	719	10	2.4	740	33	2.3	2,047	2	7.6
Cyclops vernalis							35	0	0.1
Tropocyclops prasinus mexicanus	354	63	1.2	1,024	21	3.2	434	40	1.6
Calanoid copepods									
Immature copepodids	10,642	2	36.2	12,553	1	38.7	4,822	18	17.9
Diaptomus ashlandi	451	11	1.5	417	26	1.3	130	28	0.5
Diaptomus minutus	299	15	1.0	436	6	1.3	130	85	0.5
Diaptomus oregonensis	1,006	11	3.4	2,257	20	7.0	1,526	14	5.7
Diaptomus sicilis	195	9	0.7	57	46	0.2	35	76	0.1
Epischura lacustris	61	23	0.2	66	26	0.2	312	16	1.2
Eurytemora affinis				9	184	0.0	52	141	0.2
Limnocalanus macrurus	43	61	0.1	9	184	0.0			
Harpacticoid copepods									
Canthocamptus sp.							9	164	0.0
Cladocerans									
Bosmina longirostris	110	32	0.4	417	13	1.3	165	22	0.6
Ceriodaphnia quadrangula									
Chydorus sphaericus							17	153	0.1
Daphnia galeata mendotae	194	9	0.7	853	35	2.6	754	24	2.8
Daphnia retrocurva	219	71	0.7	588	41	1.8	1,214	36	4.5
Diaphanosoma leuchtenbergianum	85	20	0.3	246	44	0.8	139	53	0.5
Eubosmina coregoni	457	29	1.6	2,086	18	6.4	1,917	10	7.1
Holopedium gibberum	37	47	0.1	57	46	0.2	35	0	0.1
Leptodora kindtii							9	164	0.0
Polyphemus pediculus									
Rotifers									
Asplanchna sp.									
TOTAL	29,36[illegible]			32,454			26,929		
mg/m^3	58	2		91.0	9		109	1	
μg/individual	1.9	7		2.8	10		4.0	7	

Table 28. Zooplankton genus counts (ind/m^3), coefficients of variation between duplicate subsamples, percent composition by genus, total zooplankton weight (mg/m^3), and mean zooplankter weight (μg/ind) for 41 stations sampled on 12 April 1972.

	DC-4			DC-3			DC-1			NDC-.25-1			SDC-.25-1		
Genus	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%
Copepod nauplii	1,825		30.7	1,154		20.3	506		32.4	1,466		19.3	1,082		16.3
Cyclopoid copepods															
Immature copepodids	639		10.7	405		7.1	166		10.6	425		5.6	565		8.5
Cyclops	1,591		26.7	2,788		49.0	432		27.7	4,388		57.6	3,369		50.9
Tropocyclops	17		0.3	54		0.9				52		0.7			
Calanoid copepods															
Immature copepodids	63		1.1	27		0.5	28		1.8	17		0.2	90		1.4
Diaptomus	1,774		29.8	1,181		20.8	377		24.2	1,231		16.2	1,437		21.7
Epischura															
Eurytemora															
Limnocalanus	34		0.6	20		0.4	5		0.3				47		0.7
Harpacticoid copepods															
Canthocamptus	6		0.1	34		0.6				26		0.3			
Cladocerans															
Bosmina				7		0.1									
Ceriodaphnia													5		0.1
Chydorus							37		2.4	9		0.1	18		0.3
Daphnia				7		0.1									
Diaphanosoma															
Eubosmina				7		0.1							5		0.1
Holopedium															
Leptodora															
Polyphemus															
Rotifers															
Asplanchna							5		0.2				2		0.0
TOTAL	5,949			5,684			1,561			7,614			6,621		
mg/m^3															
μg/individual															

Table 28, cont'd.

Genus	NDC-.5-3 #/m^3	cv	%	NDC-.5-2 #/m^3	cv	%	NDC-.5-1 #/m^3	cv	%	NDC-1-3 #/m^3	cv	%	NDC-1-2 #/m^3	cv	%
Copepod nauplii	881		13.9	2,000		31.9	2,576		25.3	1,445		33.2	376		26.7
Cyclopoid copepods															
Immature copepodids	606		9.5	738		11.8	1,067		10.5	368		8.5	154		10.9
Cyclops	3,442		54.2	1,428		22.8	1,509		14.8	1,290		29.6	424		30.1
Tropocyclops	16		0.3										9		0.6
Calanoid copepods															
Immature copepodids	105		1.7	88		1.4	286		2.8	29		0.7	10		0.7
Diaptomus	1,253		19.7	1,574		25.1	4,267		41.9	1,154		26.5	400		28.4
Epischura															
Eurytemora															
Limnocalanus	8		0.1	286		4.6	286		2.8	68		1.6	17		1.2
Harpacticoid copepods															
Canthocamptus	16		0.3	72		1.1	78		0.8				12		0.9
Cladocerans															
Bosmina	8		0.1	23		0.4	26		0.3						
Ceriodaphnia															
Chydorus				46		0.7	52		0.5				3		0.2
Daphnia							26		0.3						
Diaphanosoma															
Eubosmina	16		0.3	3		0.0							2		0.1
Holopedium															
Leptodora															
Polyphemus															
Rotifers															
Asplanchna				6		0.1									
TOTAL	6,351			6,264			10,173			4,355			1,407		
mg/m^3															
μg/individual															

Table 28, cont'd.

Genus	NDC-1-1			NDC-2-4			NDC-2-3			NDC-2-2*			NDC-2-1		
	#/m³	cv	%	#/m³	cv	%	#/m³	cv	%	#/m³	cv	%	#/m³	cv	%
Copepod nauplii				219		9.8	1,487		15.0	403		19.8	213		32.5
Cyclopoid copepods															
Immature copepodids				122		5.5	616		6.2	173		8.5	102		15.5
Cyclops	597		25.2	920		41.1	5,544		56.0	377		18.5	33		5.0
Tropocyclops	6		0.3				45		0.5						
Calanoid copepods															
Immature copepodids				95		4.2	75		0.8	30		1.5	29		4.3
Diaptomus	1,594		67.3	852		38.1	1,961		19.8	923		45.2	222		33.8
Epischura															
Eurytemora															
Limnocalanus	159		6.7	25		1.1	60		0.6	67		3.3	18		2.7
Harpacticoid copepods															
Canthocamptus	6		0.3	3		0.1	60		0.6	33		1.6	27		4.1
Cladocerans															
Bosmina	6		0.3				38		0.4				2		0.3
Ceriodaphnia										33		1.6			
Chydorus							15		0.2				4		0.6
Daphnia															
Diaphanosoma															
Eubosmina				1		0.0									
Holopedium															
Leptodora															
Polyphemus															
Rotifers															
Asplanchna													4		0.6
TOTAL	2,368			2,237			9,901			2,040			656		
mg/m³															
μg/individual															

*Flowmeter reading not taken; volume filtered estimated from depth.

Table 28, cont'd.

Genus	NDC-7-4			NDC-7-3			NDC-7-2		
	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%
Copepod nauplii	10		0.6	687		29.7	1,562		39.3
Cyclopoid copepods									
Immature copepodids	27		1.7	329		14.2	276		6.9
Cyclops	556		36.0	622		26.9	1,114		28.0
Tropocyclops									
Calanoid copepods									
Immature copepodids	5		0.3	42		1.8	3		0.1
Diaptomus	894		57.9	602		26.0	894		22.5
Epischura									
Eurytemora									
Limnocalanus	48		3.1	18		0.8	66		1.7
Harpacticoid copepods									
Canthocamptus	2		0.1	4		0.2			
Cladocerans									
Bosmina				4		0.2	3		0.1
Ceriodaphnia									
Chydorus				4		0.2	50		1.3
Daphnia				2		0.1	6		0.2
Diaphanosoma									
Eubosmina	2		0.1				3		0.1
Holopedium									
Leptodora									
Polyphemus									
Rotifers									
Asplanchna									
TOTAL	1,544			2,315			3,977		
mg/m^3									
μg/individual									

Table 28, cont'd.

Genus	SDC-.5-3			SDC-.5-2			SDC-.5-1			SDC-1-3			SDC-1-2		
	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%
Copepod nauplii	2,264		33.1	57		6.9	447		17.9	921		29.7	1,584		34.8
Cyclopoid copepods															
Immature copepodids	901		13.1	47		5.7	276		11.1	209		6.7	497		10.9
Cyclops	2,238		32.6	452		54.5	886		35.5	1,024		33.1	797		17.5
Tropocyclops	70		1.0										41		0.9
Calanoid copepods															
Immature copepodids	52		0.8				41		1.6	96		3.1	31		0.7
Diaptomus	1,224		17.9	232		28.0	741		29.7	801		25.9	1,429		31.4
Epischura															
Eurytemora															
Limnocalanus	9		0.1	35		4.2	41		1.6	33		1.1	93		2.0
Harpacticoid copepods															
Canthocamptus	52		0.8				41		1.6				41		0.9
Cladocerans															
Bosmina	9		0.1	8		1.0	5		0.2	8		0.3	21		0.5
Ceriodaphnia															
Chydorus	17		0.2				18		0.7	4		0.1			
Daphnia	9		0.1							1		0.0	10		0.2
Diaphanosoma															
Eubosmina															
Holopedium															
Leptodora															
Polyphemus															
Rotifers															
Asplanchna															
TOTAL	6,855			831			2,496			3,098			4,546		
mg/m^3															
μg/individual															

Table 28, cont'd.

Genus	SDC-1-1			SDC-2-4			SDC-2-3			SDC-2-2			SDC-2-1		
	#/m³	cv	%	#/m³	cv	%	#/m³	cv	%	#/m³	cv	%	#/m³	cv	%
Copepod nauplii	21		0.8	1,115		27.6	3,114		34.4	74		5.1	37		1.6
Cyclopoid copepods															
Immature copepodids	45		1.8	394		9.7	1,138		12.6	204		14.0	133		5.7
Cyclops	816		32.7	1,273		31.5	2,327		25.7	370		25.3	592		25.5
Tropocyclops							57		0.6						
Calanoid copepods															
Immature copepodids	11		0.4	77		1.9	93		1.0	39		2.7	64		2.8
Diaptomus	1,453		58.2	1,124		27.8	2,133		23.6	693		47.4	1,323		57.0
Epischura															
Eurytemora															
Limnocalanus	139		5.6	38		0.9	122		1.3	77		5.3	155		6.7
Harpacticoid copepods															
Canthocamptus				10		0.2	21		0.2						
Cladocerans															
Bosmina	11		0.4	5		0.1	7		0.1	3		0.2	5		0.2
Ceriodaphnia															
Chydorus							29		0.3				5		0.2
Daphnia							7		0.1						
Diaphanosoma															
Eubosmina				5		0.1							5		0.2
Holopedium															
Leptodora															
Polyphemus															
Rotifers															
Asplanchna															
TOTAL	2,496			4,041			9,048			1,461			2,320		
mg/m³															
µg/individual															

Table 28, cont'd.

Genus	SDC-4-4			SDC-4-3			SDC-4-2			SDC-4-1			SDC-7-5		
	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%
Copepod nauplii	244		6.9	1,465		21.3	1,069		27.7	1,247		27.9	695		15.6
Cyclopoid copepods															
Immature copepodids	66		1.9	511		7.4	379		9.8	370		8.3	186		4.2
Cyclops	843		23.7	2,968		43.1	1,009		26.1	1,746		39.1	1,028		23.1
Tropocyclops	9		0.3	60		0.9	21		0.5						
Calanoid copepods															
Immature copepodids	23		0.6	75		1.1	45		1.2	69		1.5	34		0.8
Diaptomus	2,299		64.7	1,725		25.0	1,138		29.5	920		20.6	2,461		55.3
Epischura															
Eurytemora															
Limnocalanus	53		1.5	56		0.7	62		1.6	26		0.6	49		1.1
Harpacticoid copepods															
Canthocamptus	11		0.3	31		0.4	88		2.3	17		0.4			
Cladocerans															
Bosmina				6		0.1	21		0.5						
Ceriodaphnia															
Chydorus	3		0.1				21		0.5	69		1.5			
Daphnia							6		0.2						
Diaphanosoma															
Eubosmina															
Holopedium															
Leptodora															
Polyphemus															
Rotifers															
Asplanchna															
TOTAL	3,552			6,892			3,859			4,464			4,453		
mg/m^3															
µg/individual															

Table 28, cont'd.

	SDC-7-4			SDC-7-3			SDC-7-2		
Genus	#/m³	cv	%	#/m³	cv	%	#/m³	cv	%
Copepod nauplii	172		27.0	911		28.3	600		26.0
Cyclopoid copepods									
Immature copepodids	64		10.0	345		10.7	393		17.0
Cyclops	192		30.1	968		30.1	490		21.2
Tropocyclops				74		2.3			
Calanoid copepods									
Immature copepodids	6		0.9	41		1.3	20		0.9
Diaptomus	199		31.2	829		25.8	783		33.9
Epischura									
Eurytemora									
Limnocalanus	5		0.8	25		0.8	20		0.9
Harpacticoid copepods									
Canthocamptus				25		0.8			
Cladocerans									
Bosmina									
Ceriodaphnia									
Chydorus									
Daphnia									
Diaphanosoma									
Eubosmina									
Holopedium									
Leptodora									
Polyphemus									
Rotifers									
Asplanchna									
TOTAL	638			3,218			2,307		
mg/m³									
µg/individual									

Table 29. Zooplankton genus counts (ind/m^3), coefficients of variation between duplicate subsamples, percent composition by genus, total zooplankton weight (mg/m^3), and mean zooplankter weight (μg/ind) for 5 stations sampled on 4 May 1972.

Genus	DC-4			DC-3			DC-1			NDC-.5-2			SDC-.5-2		
	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%
Copepod nauplii	6,495	4	76.8	4,800	0	76.0	2,649	8	83.4	1,277	2	80.7	3,483	5	81.6
Cyclopoid copepods															
Immature copepodids	64	3	0.8	231	0	3.7	142	24	4.5	146	4	9.2	125	28	2.9
Cyclops	462	6	5.5	181	4	2.9	163	8	5.1	48	19	3.0	167	57	3.9
Tropocyclops															
Calanoid copepods															
Immature copepodids	653	22	7.7	621	22	9.8	50	42	1.6	44	34	2.8	150	16	3.5
Diaptomus	626	0	7.4	365	0	5.8	119	14	3.7	27	12	1.7	267	18	6.3
Epischura															
Eurytemora															
Limnocalanus															
Harpacticoid copepods															
Canthocamptus	5	189	0.1												
Cladocerans															
Bosmina	37	66	0.4	41	0	0.6	36	0	1.1	31	14	2.0	50	48	1.2
Ceriodaphnia															
Chydorus	5	189	0.1	27	47	0.4	6	151	0.2	8	0	0.5	25	47	0.6
Daphnia	58	42	0.7	23	76	0.4	6	151	0.2						
Diaphanosoma															
Eubosmina	27	75	0.3	13	25	0.2									
Holopedium	5	189	0.1												
Leptodora															
Polyphemus															
Rotifers															
Asplanchna	16	63	0.2	9	50	0.1	6	151	0.2						
TOTAL	8,453			6,312			3,177			1,583			4,267		
mg/m^3															
μg/individual															

Table 30. Zooplankton genus counts (ind/m^3), coefficients of variation between duplicate subsamples, percent composition by genus, total zooplankton weight (mg/m^3), and mean zooplankter weight (μg/ind) for 5 stations sampled on 11 June 1972.

Genus	DC-4 #/m^3	DC-4 cv	DC-4 %	DC-3 #/m^3	DC-3 cv	DC-3 %	DC-1 #/m^3	DC-1 cv	DC-1 %	NDC-.5-2 #/m^3	NDC-.5-2 cv	NDC-.5-2 %	SDC-.5-2 #/m^3	SDC-.5-2 cv	SDC-.5-2 %
Copepod nauplii	637	39	2.8	916	16	3.1	235	15	4.7	502	58	5.3	337	117	6.0
Cyclopoid copepods															
Immature copepodids	707	16	3.1	1,427	25	4.8	677	25	13.4	1,160	7	12.3	461	44	8.3
Cyclops	1,704	9	7.4	1,157	6	3.9	332	16	6.6	967	13	10.3	549	3	9.8
Tropocyclops															
Calanoid copepods															
Immature copepodids	933	6	4.1	1,082	12	3.6	486	5	9.6	738	32	7.8	49	71	0.9
Diaptomus	1,299	6	5.7	871	39	2.9	275	8	5.5	831	21	8.8	454	16	8.1
Epischura															
Eurytemora	43	61	0.2												
Limnocalanus							9	88	0.2						
Harpacticoid copepods															
Canthocamptus	195	4	0.9	75	85	0.2	35	9	0.7	105	8	1.1	53	12	0.9
Cladocerans															
Bosmina	15,573	23	67.9	19,020	5	63.6	2,058	15	40.9	2,784	20	29.6	2,311	4	41.4
Ceriodaphnia															
Chydorus	30	0	0.1	135	16	0.5	93	19	1.8	205	4	2.2	130	0	2.3
Daphnia	27	77	0.1	45	47	0.1	9	36	0.2						
Diaphanosoma															
Eubosmina															
Holopedium							3	128	0.1						
Leptodora															
Polyphemus															
Rotifers															
Asplanchna	1,765	12	7.7	5,153	21	17.2	825	20	16.4	2,109	7	22.4	1,233	12	22.1
TOTAL	22,918			29,912			5,037			9,401			5,577		
mg/m^3	98	9		200	43		69	-		72	2		53	17	
μg/individual	4.4	5		6.8	49		13.7	-		7.6	0		9.5	19	

Table 31. Zooplankton genus counts (ind/m^3), coefficients of variation between duplicate subsamples, percent composition by genus, total zooplankton weight (mg/m^3), and mean zooplankter weight (μg/ind) for 23 stations sampled on 16 July 1972.

Genus	DC-4			DC-3			DC-1			NDC-.5-2			SDC-.5-2		
	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%
Copepod nauplii	6,223	103	4.7	11,936	34	14.9	2,379	15	5.5	5,096	23	9.7	11,872	33	15.3
Cyclopoid copepods															
Immature copepodids	6,836	34	5.2	2,147	31	2.9	751	20	1.7	593	0	1.1	5,379	10	7.0
Cyclops	43,138	2	32.6	3,291	24	4.1	544	7	1.3	1,007	8	1.9	834	47	1.1
Tropocyclops	94	141	0.1	28	142	0.0	105	47	0.2	237	141	0.5			
Calanoid copepods															
Immature copepodids	7,025	76	5.3	7,529	28	9.4	2,372	0	5.5	3,911	25	7.5	6,956	13	9.0
Diaptomus	8,439	34	6.4	948	124	1.2	84	71	0.2	355	0	0.7	92	146	0.1
Epischura															
Eurytemora	71	141	0.1	167	47	0.2	7		0.0				278	141	0.4
Limnocalanus															
Harpacticoid copepods															
Canthocamptus															
Cladocerans															
Bosmina	57,187	5	43.3	48,634	34	60.8	33,775	1	78.5	35,437	16	67.6	47,118	20	60.9
Ceriodaphnia							18	31	0.0						
Chydorus	24	142	0.0	84	141	0.1	25	60	0.1						
Daphnia	1,060	22	0.8	892	53	1.1	137	18	0.3						
Diaphanosoma	24	142	0.0				11	30	0.0	119	141	0.2			
Eubosmina	24	142	0.0												
Holopedium							11	30	0.0						
Leptodora	24	142	0.0				11	140	0.0						
Polyphemus	519	77	0.4	390	61	0.5	400	3	0.9	1,363	43	2.6			
Rotifers															
Asplanchna	1,532	76	1.2	3,988	11	5.0	2,351	23	5.5	4,326	1	8.2	4,822	16	6.2
TOTAL	132,220			80,034			43,006			52,444			77,351		
mg/m^3	309	15		152	8		109	13		185	2		497	1	
μg/individual	2.1	7		1.5	9		2.5	8		3.6	2		6.3	18	

Table 31, cont'd.

Genus	NDC-1-2			NDC-1-1			NDC-2-3			NDC-2-1			NDC-4-4		
	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%
Copepod nauplii	29,519	5	16.2	2,456	25	8.4	10,699	10	13.4	758	51	1.7	17,094	35	14.8
Cyclopoid copepods															
Immature copepodids	6,005	37	3.3	128	31	0.4	2,757	20	3.5	982	35	2.3	16,137	7	13.9
Cyclops	3,445	32	1.9	353	3	1.2	2,560	15	3.2	257	13	0.6	41,026	10	35.4
Tropocyclops				17	50	0.1	131	71	0.2						
Calanoid copepods															
Immature copepodids	15,581	32	8.6	2,225	31	7.6	9,288	12	11.7	1,740	22	4.0	7,877	99	6.8
Diaptomus	1,138	31	0.6	122	26	0.4	558	8	0.7	126	16	0.3	10,338	8	8.9
Epischura															
Eurytemora	253	35	0.1	3	197	0.0	66	142	0.1						
Limnocalanus													684	62	0.6
Harpacticoid copepods															
Canthocamptus															
Cladocerans															
Bosmina	116,812	11	64.3	22,461	3	76.5	48,115	52	60.4	37,904	8	87.1	22,099	3	19.1
Ceriodaphnia	32	142	0.0							5	135	0.0			
Chydorus	32	142	0.0	3	197	0.0									
Daphnia	537	25	0.3	100	6	0.3	1,050	177	1.3	37	106	0.1	547	99	0.5
Diaphanosoma				2	197	0.0	33	142	0.0	5	135	0.0			
Eubosmina							33	142	0.0						
Holopedium				14	23	0.0									
Leptodora				3	197	0.0									
Polyphemus	1,170	27	0.6	386	11	1.3	657	42	0.8	505	34	1.2	55	0	0.0
Rotifers															
Asplanchna	7,174	53	3.9	1,097	64	3.7	3,676	23	4.6	1,188	72	2.7			
TOTAL	181,728			29,369			79,623			43,509			115,857		
mg/m^3	198	1		97	3		123	10		102	17		-	-	
μg/individual	1.1	7		3.2	4		1.6	35		2.3	9		-	-	

Table 31, cont'd.

Genus	NDC-4-3 #/m^3	cv	%	NDC-4-1 #/m^3	cv	%	NDC-7-5 #/m^3	cv	%	NDC-7-3 #/m^3	cv	%
Copepod nauplii	3,987	111	7.0	2,384	54	3.1	4,895	11	4.5	25,381	21	14.0
Cyclopoid copepods												
Immature copepodids	4,800	28	8.5	1,004	44	1.3	7,710	21	7.0	5,543	7	3.1
Cyclops	7,771	23	13.7	973	9	1.3	28,199	6	25.7	1,750	47	1.0
Tropocyclops	102	0	0.2	31	0	0.0						
Calanoid copepods												
Immature copepodids	5,105	25	9.0	5,616	33	7.3	11,349	29	10.4	18,379	20	10.1
Diaptomus	1,625	4	2.9	204	76	0.3	17,283	5	15.8	1,167	0	0.6
Epischura	25	141	0.0									
Eurytemora												
Limnocalanus							43	142	0.0			
Harpacticoid copepods												
Canthocamptus												
Cladocerans												
Bosmina	31,187	3	55.1	63,435	10	82.3	36,472	29	33.3	117,862	6	65.0
Ceriodaphnia												
Chydorus												
Daphnia				16	143	0.0	2,339	31	2.1	2,626	16	1.4
Diaphanosoma				31	0	0.0						
Eubosmina												
Holopedium	76	141	0.1				87	0	0.1			
Leptodora							130	47	0.1			
Polyphemus	356	20	0.6	973	32	1.3	260	0	0.2	2,917	0	1.6
Rotifers												
Asplanchna	1,600	56	2.8	2,431	52	3.2	866	42	0.8	5,835	14	3.2
TOTAL	56,634			77,097			109,633			181,460		
mg/m^3	153	14		176	0		398	15		440	3	
µg/individual	2.4	15		2.2	10		3.8	66		2.5	3	

Table 31, cont'd.

Genus	SDC-1-2 #/m³	cv	%	SDC-1-1 #/m³	cv	%	SDC-2-3 #/m³	cv	%	SDC-2-1 #/m³	cv	%	SDC-4-4 #/m³	cv	%
Copepod nauplii	9,486	35	11.8	13,970	13	8.8	9,415	31	15.3	1,019	16	6.2	8,308	28	3.6
Cyclopoid copepods															
Immature copepodids	4,515	45	5.6	2,133	23	1.3	738	71	1.2	82	71	0.5	17,665	25	7.7
Cyclops	1,284	5	1.6	3,166	12	2.0	903	64	1.5	62	16	0.4	67,517	26	29.4
Tropocyclops				275	71	0.2	82	71	0.1						
Calanoid copepods															
Immature copepodids	4,971	26	6.2	7,019	42	4.4	8,246	23	13.4	1,019	26	6.2	20,846	26	9.1
Diaptomus	207	28	0.3	1,170	8	0.7	533	0	0.9	212	32	1.3	31,625	10	13.8
Epischura															
Eurytemora	124	47	0.2				41	142	0.1				261	60	0.1
Limnocalanus													112	144	0.0
Harpacticoid copepods															
Canthocamptus													37	145	0.0
Cladocerans															
Bosmina	55,840	26	69.5	119,467	12	75.0	36,677	14	59.5	11,781	18	71.8	80,392	31	35.0
Ceriodaphnia	124	47	0.2				21	141	0.0				111	48	0.0
Chydorus	124	47	0.2	69	141	0.0				21	44	0.1			
Daphnia	207	28	0.3	344	28	0.2	226	90	0.4	14	0	0.1	2,619	12	1.1
Diaphanosoma															
Eubosmina															
Holopedium							21	141	0.0						
Leptodora															
Polyphemus	539	11	0.7	2,065	47	1.3	595	44	1.0	855	3	5.2			
Rotifers															
Asplanchna	2,941	42	3.7	9,703	35	6.1	4,103	24	6.7	1,340	39	8.2	261	60	0.1
TOTAL	80,362			159,381			61,599			16,405			229,754		
mg/m³	179	14		363	18		107	2		50	15		786	15	
µg/individual	2.9	30		2.1	7		1.6	18		3.0	5		3.9	9	

Table 31, cont'd.

Genus	SDC-4-3 #/m³	SDC-4-3 cv	SDC-4-3 %	SDC-4-1 #/m³	SDC-4-1 cv	SDC-4-1 %	SDC-7-5 #/m³	SDC-7-5 cv	SDC-7-5 %	SDC-7-3 #/m³	SDC-7-3 cv	SDC-7-3 %
Copepod nauplii	12,621	46	10.0	1,216	57	3.4	5,768	29	9.1	6,356	17	6.4
Cyclopoid copepods												
Immature copepodids	4,147	60	3.3	524	66	1.5	5,065	7	8.0	2,177	6	2.2
Cyclops	6,534	3	5.2	80	9	0.2	11,251	9	17.7	522	0	0.5
Tropocyclops												
Calanoid copepods												
Immature copepodids	5,997	29	4.8	1,343	26	3.8	3,587	18	5.7	4,963	7	5.0
Diaptomus	2,506	3	2.0	61	12	0.2	7,187	2	11.3	348	141	0.4
Epischura												
Eurytemora	209	20	0.2	9	147	0.0				522	94	0.5
Limnocalanus												
Harpacticoid copepods												
Canthocamptus												
Cladocerans												
Bosmina	89,749	9	71.2	28,229	3	80.0	27,769	14	43.8	82,373	51	83.1
Ceriodaphnia							83	20	0.1			
Chydorus	30	142	0.0	9	0	0.0				87	141	0.1
Daphnia	955	44	0.8	56	71	0.2	1,311	3	2.1	435	28	0.4
Diaphanosoma												
Eubosmina												
Holopedium	60	141	0.0				119	85	0.2			
Leptodora							24	0	0.0			
Polyphemus	865	44	0.7	931	23	2.6				522	47	0.5
Rotifers												
Asplanchna	2,357	41	1.9	2,835	13	8.0	1,228	18	1.9	784	79	0.8
TOTAL	126,054			35,293			63,392			99,091		
mg/m³	156	6		105	25		165	9		378	18	
µg/individual	1.2	12		2.9	22		2.6	19		4.0	28	

Table 32. Zooplankton genus counts (ind/m^3), coefficients of variation between duplicate subsamples, percent composition by genus, total zooplankton weight (mg/m^3), and mean zooplankter weight (μg/ind) for 4 stations sampled on 11 August 1972.

Genus	DC-4			DC-3			NDC-.5-2			SDC-.5-2		
	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%
Copepod nauplii	3,016	37	2.0	2,964	21	1.6	10,240	9	1.8	2,726	18	2.1
Cyclopoid copepods												
Immature copepodids	9,129	28	6.2	9,611	33	5.3	20,821	26	3.6	4,583	46	3.6
Cyclops	13,336	40	9.0	13,833	6	7.6	13,995	66	2.4	8,099	20	6.3
Tropocyclops	953	47	0.6	539	0	0.3	3,072	16	0.5	830	47	0.6
Calanoid copepods												
Immature copepodids	13,098	5	8.8	11,408	37	6.3	20,480	57	3.5	11,299	3	8.8
Diaptomus	1,820	18	1.2	2,605	5	1.4	3,072	47	0.5	632	35	0.5
Epischura												
Eurytemora	159	41	0.1	269	47	0.1	341	141	0.1	277	20	0.2
Limnocalanus												
Harpacticoid copepods												
Canthocamptus												
Cladocerans												
Bosmina	88,270	30	59.5	126,383	8	69.4	447,829	9	76.7	86,992	28	67.7
Ceriodaphnia	397	28	0.3	359	0	0.2	683	141	0.1	119	47	0.1
Chydorus												
Daphnia	5,001	33	3.4				9,557	30	1.6	3,832	10	3.0
Diaphanosoma	79	141	0.1	629	61	0.3				79	0	0.1
Eubosmina	159		0.1									
Holopedium	714	47	0.5	539	47	0.3	2,731	35	0.5	198	28	0.2
Leptodora	79	141	0.1				341	141	0.1			
Polyphemus	397	28	0.3				4,437	11	0.8	593	28	0.5
Rotifers												
Asplanchna	11,669	31	7.9	12,845	11	7.1	46,421	4	7.9	8,178	17	6.4
TOTAL	148,360			181,984			584,021			128,513		
mg/m^3	323	17		252	53		635	26		258	23	
μg/individual	2.1	7		1.3	65		1.0	14		1.9	7	

Table 33. Zooplankton genus counts (ind/m^3), coefficients of variation between duplicate subsamples, percent composition by genus, total zooplankton weight (mg/m^3), and mean zooplankter weight (µg/ind) for 4 stations sampled on 8 September 1972.

Genus	DC-4			DC-3			NDC-.5-2			SDC-.5-2		
	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%
Copepod nauplii	4,437	27	4.6	6,954	0	12.6	3,396	16	25.5	5,440	30	13.9
Cyclopoid copepods												
Immature copepodids	2,987	20	3.1	1,579	32	2.9	293	8	2.2	733	49	1.9
Cyclops	24,661	22	25.4	4,793	30	8.7	164	27	1.2	1,040	51	2.7
Tropocyclops	683	71	0.7	831	19	1.5	178	0	1.3	200	47	0.5
Calanoid copepods												
Immature copepodids	36,011	38	37.1	24,851	6	44.9	4,880	10	36.7	10,453	31	26.6
Diaptomus	2,645	50	2.7	776	40	1.4	156	44	1.2	93	61	0.2
Epischura												
Eurytemora				55	0	0.1						
Limnocalanus												
Harpacticoid copepods												
Canthocamptus												
Cladocerans												
Bosmina	171	141	0.2	720	33	1.3	693	38	5.2	2,200	51	5.6
Ceriodaphnia										13	144	0.0
Chydorus				28	142	0.1	58	33	0.4			
Daphnia	18,176	31	18.8	11,082	32	20.0	2,840	15	21.4	18,187	5	46.4
Diaphanosoma	853	28	0.9	665	10	1.2	31	0	0.2	40	48	0.1
Eubosmina	1,621	7	1.7	748	12	1.4	62	20	0.5	160	94	0.4
Holopedium	4,267	6	4.4	1,358	29	2.5	244	28	1.8	320	59	0.8
Leptodora	85	141	0.1	139	85	0.3						
Polyphemus				28	142	0.0	9	147	0.1	27	141	0.1
Rotifers												
Asplanchna	341	141	0.4	748	16	1.4	289	11	2.2	320	59	0.8
TOTAL	96,938			55,356			13,297			39,226		
mg/m^3	350	3		152	30		98	12		182	12	
µg/individual	3.0	12		2.5	23		6.8	7		4.4	11	

Table 34. Zooplankton genus counts (ind/m^3), coefficients of variation between duplicate subsamples, percent composition by genus. total zooplankton weight (mg/m^3), and mean zooplankter weight (μg/ind) for 22 stations sampled on 15 October 1972.

Genus	DC-4			DC-3			NDC-.5-2			SDC-.5-2		
	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%
Copepod nauplii	1,477	16	4.8	1,108	81	2.5	3,538	5	11.4	1,498	53	2.6
Cyclopoid copepods												
Immature copepodids	4,037	16	13.2	5,198	13	11.6	6,049	2	19.4	3,271	44	5.7
Cyclops	3,577	4	11.7	4,467	17	10.0	3,186	14	10.2	1,325	4	2.3
Tropocyclops	667	16	2.2	354	75	0.8	486	39	1.6	290	3	0.5
Calanoid copepods												
Immature copepodids	12,220	18	40.1	21,828	2	48.8	4,456	8	14.3	2,392	16	4.1
Diaptomus	339	59	1.1	224	89	0.5	149	39	0.5	118	7	0.2
Epischura	55	26	0.2	29	28	0.1	27	142	0.1			
Eurytemora	55	85	0.2				13	141	0.0	8	140	0.0
Limnocalanus												
Harpacticoid copepods												
Canthocamptus				12	144	0.0				16	43	0.0
Cladocerans												
Bosmina	2,472	36	8.1	3,067	11	6.9	7,602	3	24.4	42,447	30	73.5
Ceriodaphnia				29	142	0.1				24	47	0.0
Chydorus	66	94	0.2	83	101	0.2	67	28	0.2	16	143	0.0
Daphnia	3,785	15	12.4	4,467	7	10.0				1,914	14	3.3
Diaphanosoma	514	21	1.7	289	61	0.6	149	64	0.5	118	133	0.3
Eubosmina				2,734	43	6.1	4,982	0	16.0	3,765	21	6.5
Holopedium	1,094	14	3.6	660	20	1.5	338	6	1.1	424	5	0.7
Leptodora				59	28	0.1	13	141	0.0	55	20	0.1
Polyphemus										8	140	0.0
Rotifers												
Asplanchna	142	33	0.5	136	104	0.3	81	0	0.3	16	143	0.0
TOTAL	30,501			44,752			31,135			57,772		
mg/m^3	-			-			-			-		
μg/individual	-			-			-			-		

Table 34 cont'd.

Genus	NDC-1-2			NDC-1-1			NDC-2-3			NDC-2-1			NDC-4-4		
	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%
Copepod nauplii	5,324	8	13.1	2,633	9	10.2	1,632	4	5.1	2,011	43	5.9	925	26	2.4
Cyclopoid copepods															
Immature copepodids	4,776	7	11.7	3,300	21	12.7	7,458	9	23.4	5,090	16	15.0	4,351	21	11.3
Cyclops	3,836	38	9.4	2,033	7	7.8	1,331	35	4.2	945	50	2.8	6,957	9	18.1
Tropocyclops	470	47	1.2	433	11	1.7	392	69	1.2	335	13	1.0	336	35	0.9
Calanoid copepods															
Immature copepodids	12,996	9	31.9	1,733	5	6.7	10,229	4	32.1	2,438	7	7.2	21,081	4	54.9
Diaptomus	157	0	0.4				100	38	0.3				357	8	0.9
Epischura							46	29	0.1						
Eurytemora															
Limnocalanus															
Harpacticoid copepods															
Canthocamptus															
Cladocerans															
Bosmina	7,672	52	18.8	12,033	27	46.5	6,291	53	19.8	17,920	11	52.8	105	141	0.3
Ceriodaphnia															
Chydorus							91	56	0.3				21	141	0.1
Daphnia	2,583	39	6.3				1,814	11	5.7	1,432	39	4.2	[illegible],732	24	7.1
Diaphanosoma	235	141	0.6				310	42	1.0	61	0	0.2	252	71	0.7
Eubosmina	2,505	18	6.2	3,233	10	12.5	1,668	8	5.2	3,291	3	9.7	715	8	1.9
Holopedium	78	142	0.2	400	94	1.5	292	44	0.9	366	71	1.1	84	141	0.2
Leptodora										30	142	0.1			
Polyphemus				67	141	0.3									
Rotifers															
Asplanchna	78	142	0.2	33	141	0.1	164	31	0.5				462	51	1.2
TOTAL	40,710			25,900			31,818			33,920			38,379		
mg/m^3	-			-			-			-			108	6	
µg/individual	-			-			-			-			2.8	10	

Table 34 cont'd.

Genus	NDC-4-3			NDC-4-1			NDC-7-5			NDC-7-3		
	#/m³	cv	%	#/m³	cv	%	#/m³	cv	%	#/m³	cv	%
Copepod nauplii	1,210	28	1.9	1,333	36	4.8	1,017	40	1.8	1,586	32	9.3
Cyclopoid copepods												
Immature copepodids	8,648	2	13.8	1,219	9	4.4	5,683	56	9.9	3,538	13	20.6
Cyclops	4,152	21	6.6	419	64	1.5	9,441	20	16.4	1,222	5	7.1
Tropocyclops	162	141	0.3	76	0	0.3	436	24	0.8	84	10	0.5
Calanoid copepods												
Immature copepodids	33,371	2	53.4	686	16	2.5	35,295	13	61.5	5,819	13	33.9
Diaptomus	219	117	0.4				345	82	0.6	189	51	1.1
Epischura	162	91	0.3							122	16	0.7
Eurytemora	29	142	0.0							40	0	0.2
Limnocalanus												
Harpacticoid copepods												
Canthocamptus												
Cladocerans												
Bosmina	2,533	22	4.1	21,257	41	77.1	272	4	0.5	1,924	20	11.2
Ceriodaphnia							18	143	0.0			
Chydorus	29	48	0.0				54	47	0.1	203	57	1.2
Daphnia	8,000	12	12.8	343	16	1.2	1,961	34	3.4	1,242	5	7.2
Diaphanosoma	410	36	0.7	76	0	0.3	254	0	0.4	176	0	1.0
Eubosmina	2,210	5	3.5	2,133	51	7.7	1,416	15	2.5	709		4.1
Holopedium	943	27	1.5	38	141	0.1	54	47	0.1	169	23	1.0
Leptodora	29	48	0.0				18	143	0.0	61	15	0.4
Polyphemus												
Rotifers												
Asplanchna	362	45	0.6				1,162	49	2.0	51	47	0.3
TOTAL	62,467			27,581			57,427			17,141		
mg/m³	-			195	4		156	15		-		
µg/individual	-			7.2	35		2.5	8		-		

Table 34 cont'd.

Genus	SDC-1-2			SDC-1-1			SDC-2-3			SDC-21-			SDC-4-4		
	#/m³	cv	%	#/m³	cv	%	#/m³	cv	%	#/m³	cv	%	#/m³	cv	%
Copepod nauplii	1,764	20	4.1	1,829	20	10.3	1,960	33	2.9	1,151	78	3.2	1,933	44	4.1
Cyclopoid copepods															
Immature copepodids	6,501	9	15.1	1,404	55	7.9	5,276	21	7.8	1,867	43	5.2	7,567	5	16.1
Cyclops	2,234	41	5.2	1,578	19	8.9	7,553	27	11.2	716	14	2.0	11,930	35	25.4
Tropocyclops	672	11	1.6	5	154	0.0	461	18	0.7	295	7	0.8	663	94	1.4
Calanoid copepods															
Immature copepodids	16,462	0	38.2	1,448	12	8.2	30,328	0	44.8	1,109	14	3.1	18,337	2	39.0
Diaptomus	143	92	0.3	8	39	0.0	519	63	0.8				663	47	1.4
Epischura	50	142	0.1				58	0	0.1						
Eurytemora	25	141	0.1	3	164	0.0	144	28	0.2						
Limnocalanus															
Harpacticoid copepods															
Canthocamptus				3	164	0.0									
Cladocerans															
Bosmina	4,132	7	9.6	5,921	41	33.4	3,690	38	5.4	19,860	3	55.3	442	35	0.9
Ceriodaphnia															
Chydorus	76	110	0.2	3	164	0.0	173	47	0.3	14	141	0.0			
Daphnia	5,409	4	12.5	1,790	12	10.1	9,946	8	14.7	1,754	21	4.9	2,927	8	6.2
Diaphanosoma	504	19	1.2	46	26	0.3	750	54	1.1	42	47	0.1	607	13	1.3
Eubosmina	3,864	2	9.0	3,516	14	19.8	6,371	12	9.4	9,053	4	25.2	1,105	28	2.4
Holopedium	1,033	13	2.4	150	39	0.8							55	141	0.1
Leptodora	67	35	0.2	35	9	0.2	58	41	0.1	14	0	0.0			
Polyphemus															
Rotifers															
Asplanchna	168	14	0.4	3	164	0.0	432	47	0.6	7	150	0.0	773	40	1.6
TOTAL	43,104			17,742			67,719			35,881			47,002		
mg/m³	-			-			346	18		-			146	28	
µg/individual							4.8	7					3.4	33	

Table 34 cont'd.

Genus	SDC-4-3 #/m³	cv	%	SDC-4-1 #/m³	cv	%	SDC-7-5 #/m³	cv	%	SDC-7-3 #/m³	cv	%
Copepod nauplii	2,726	49	3.4	369	89	0.4	2,104	3	3.3	1,333	45	4.0
Cyclopoid copepods												
Immature copepodids	25,007	21	31.3	1,326	69	1.4	6,509	17	10.3	3,653	40	11.0
Cyclops	3,615	86	4.5	588	56	0.6	10,478	4	16.5	4,533	8	13.6
Tropocyclops	1,185	85	1.5	492	16	0.5	794	14	1.3	507	67	1.5
Calanoid copepods												
Immature copepodids	32,237	12	40.4	1,026	447	1.1	30,958	10	48.9	14,587	4	43.8
Diaptomus	415	101	0.5				833	34	1.3	400	9	1.2
Epischura	415	61	0.5									
Eurytemora										107	71	0.3
Limnocalanus												
Harpacticoid copepods												
Canthocamptus										27	141	0.1
Cladocerans												
Bosmina	1,422	94	1.8	79,644	5	84.4	992	28	1.6	2,293	23	6.9
Ceriodaphnia				14	143	0.0				27	141	0.1
Chydorus	59	141	0.1				79	142	0.1	160	94	0.5
Daphnia	6,696	1	8.4	2,325	8	2.5	4,604	12	7.3	3,573	8	10.7
Diaphanosoma	1,067	63	1.3				833	7	1.3	640	59	1.9
Eubosmina	2,489	114	3.1	7,412	27	7.9	3,096	7	4.9			
Holopedium	1,600	16	2.0	957	57	1.0	953	35	1.5	987	11	3.0
Leptodora				96	20	0.1	40	141	0.1	80	47	0.2
Polyphemus				109	36	0.1						
Rotifers												
Asplanchna	889	104	1.1	27	0	0.0	1,072	37	1.7	347	33	1.0
TOTAL	79,822			94,386			63,345			33,333		
mg/m³	348			-			249	22		-		
μg/individual	4.0			-			3.7	6		-		

Table 35. Zooplankton genus counts (ind/m^3), coefficients of variations between duplicate subsamples, percent composition by genus, total zooplankton weight (mg/m^3), and mean zooplankter weight (μg/ind) for 4 stations sampled 3 November 1972.

Genus	DC-4			DC-3			NDC-.5-2			SDC-.5-2		
	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%	#/m^3	cv	%
Copepod nauplii	942	20	3.6	654	51	1.9	662	8	2.6	778	55	4.0
Cyclopoid copepods												
Immature copepodids	6,424	11	24.5	8,939	31	26.5	6,216	5	24.0	3,304	35	17.0
Cyclops	1,835	20	7.0	3,691	5	11.0	2,906	14	11.2	2,104	22	10.9
Tropocyclops	626	61	2.4	707	39	2.1	809	13	3.1	815	0	4.2
Calanoid copepods												
Immature copepodids	8,200	6	31.3	8,861	24	26.3	5,039	5	19.4	2,889	5	14.9
Diaptomus	3,266	5	12.4	2,212	8	6.6	791	10	3.1	326	6	1.7
Epischura	137	55	0.5	46	61	0.1	166	16	0.6	81	13	0.4
Eurytemora	48	71	0.2	20	142	0.1				52	21	0.3
Limnocalanus												
Harpacticoid copepods												
Canthocamptus				20	48	0.1				15	0	0.1
Cladocerans												
Bosmina	292	55	1.1	353	26	1.0	202	13	0.8	341	12	1.8
Ceriodaphnia												
Chydorus												
Daphnia	1,424	19	5.4	3,861	10	11.5	4,120	10	15.9	3,600	19	18.6
Diaphanosoma	274	12	1.0	144	90	0.4	166	79	0.6	111	9	0.6
Eubosmina	2,574	9	9.8	4,044	25	12.0	4,653	10	18.0	4,637	4	23.9
Holopedium	185	41	0.7	111	25	0.3	166	16	0.6	333	9	1.7
Leptodora	6	150	0.0	13	0	0.0						
Polyphemus												
Rotifers												
Asplanchna				7	145	0.0	18	143	0.1			
TOTAL	26,237			33,682			25,913			19,385		
mg/m^3	-			-			242	25		-		
μg/individual	-			-			9.5	40		-		

surveys, the zooplankton data (including the 1972 data) will be placed on computer cards, and machine processing will permit more rigorous comparisons with previous surveys. This has not yet been done for the 1972 data for two reasons: 1) time did not permit it, since the data were not in hand until shortly before this report was issued; and 2) machine-processing now would be of limited usefulness anyway, since these data are the first complete set to be analyzed. The 1971 data are now being enumerated as time permits (a few of these are presented below), and will be included in the next annual report. Similarly, the 1970 data, some of which have been presented in earlier survey reports, are being evaluated to determine their comparability with those collected by later methods (in 1970, a #5 mesh plankton net was used); again, some of these data are presented below.

The Seasonal Succession of Species on the DC-transect

As an introduction to the seasonal dynamics of the zooplankton Crustacea in the study area, it is convenient to consider three stations on the DC-line (DC-2, DC-5, DC-6) in some detail. These stations were selected beause they are located near the plant, species counts were available for all dates, biomass information exists for nearly all dates, and the inshore-offshore spectrum is represented. Their depths and distances from shore are shown below:

Station	Depth, ft.	Distance from shore, miles	Zone
DC-2	42	3/4	"inshore"
DC-5	84	4	"middle"
DC-6	140	7	"offshore"

It will be shown that conditions at the inshore station (DC-2) are representative of the zone from which the plant intake water will be drawn.

Let us begin by considering the total zooplankton numbers at these reference stations (Figure 9). The differences between the three zones were unimportant on the first three dates; all had 4,000 - 8,000 individuals/m^3 in April and May, and all had increased by about a factor of 4 (i.e., to 24,000 - 32,000/m^3) by June. Maximum zooplankton abundance at the middle and offshore stations (ca. 130,000/m^3) occurred in July. However, the inshore seasonal maximum of 280,000/m^3 did not occur until August, by which time abundances at the offshore and middle stations had declined slightly, to ca. 80,000 - 90,000/m^3. All three stations had ca. 50,000/m^3 in September. In October, a second, but smaller (80,000/m^3) pulse occurred inshore, but not at the other two stations. All three had about 30,000/m^3 in November. Thus the 1972 pattern may be summarized as follows: All three zones showed a similar increase from a spring minimum to a July maximum. Thereafter, the offshore and middle stations declined gradually to an autumn minimum, but the inshore station experienced a very large pulse in August, and a second but lesser one in October. The total numbers found in 1972 were very high; in fact, they may be the highest ever reported from Lake Michigan. Gannon (1972) studied the zooplankton Crustacea of Lake Michigan, Green Bay, and Milwaukee Harbor in 1969 and 1970, and never found over 100,000/m^3 in the open lake. However, he reported a September 1969 maximum of 120,000/m^3 in Milwaukee Harbor, and a July 1970 maximum of 230,000/m^3 in southern Green Bay. It seems likely that 1972 was an unusual year, perhaps because of generally cooler water temperatures. Data available from 1970 and 1971 near the Cook Plant (to be presented later) showed smaller plankton densities than those found in 1972.

The zooplankton biomass per unit volume data (Figure 10) show a seasonal pattern similar to the numerical abundances, with the annual maximum in July at the offshore and middle stations, but not until August at the inshore station. However, the relative height of the peak suggests that there is a diminution of

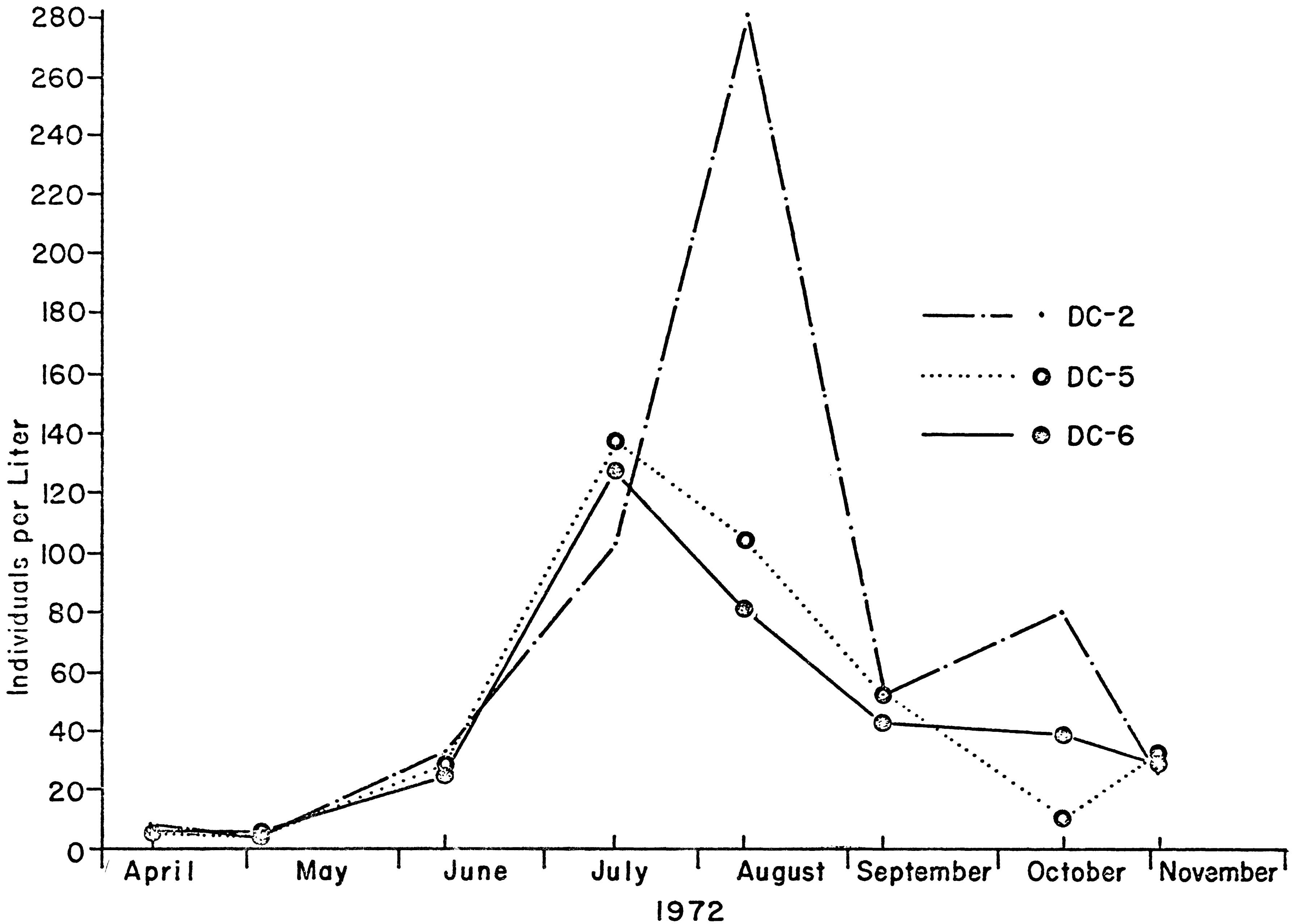

Figure 9. Total zooplankton numbers (individuals per liter) at 3 stations on 8 dates in 1972.

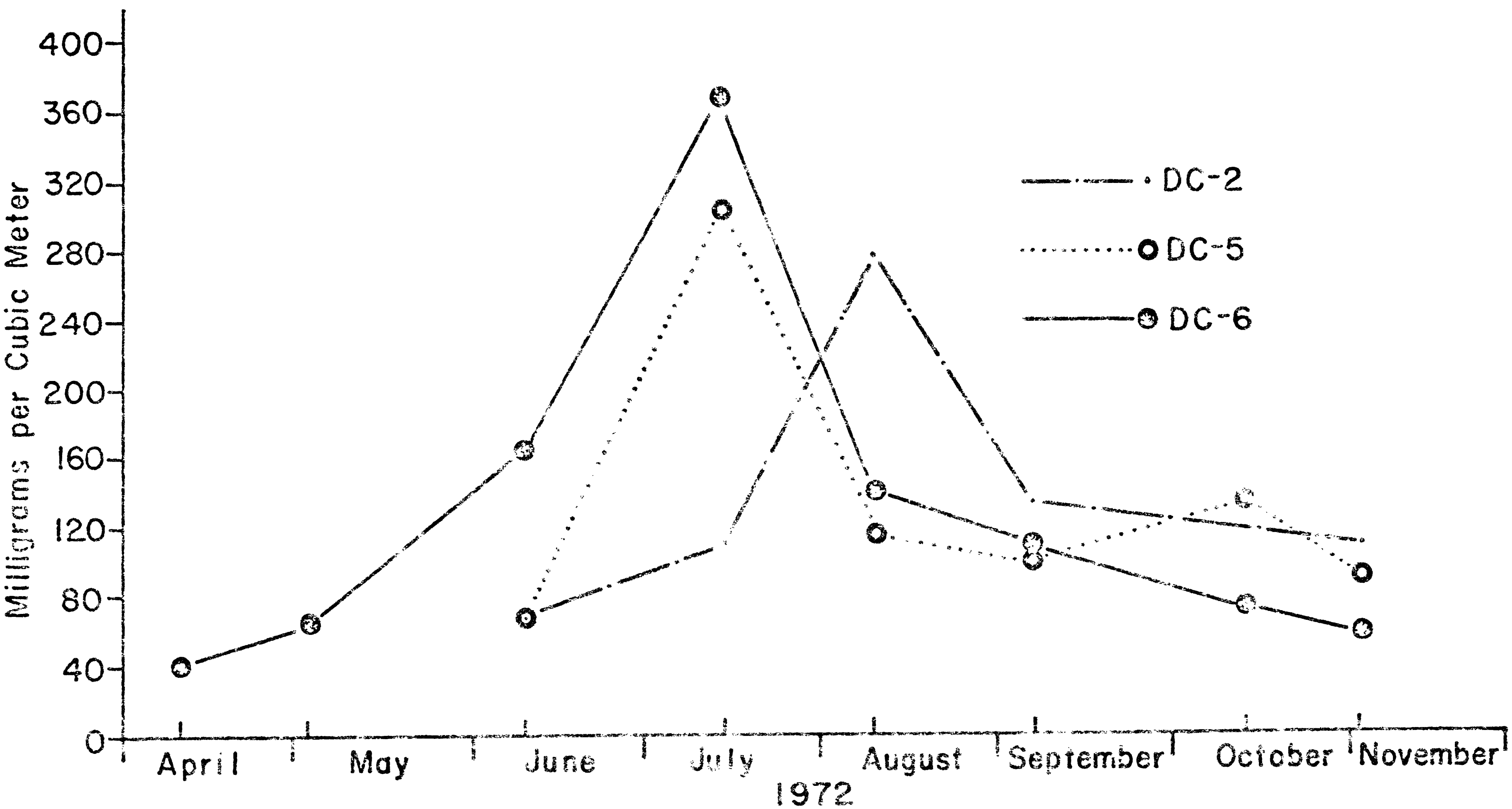

Figure 10. Zooplankton dry weight per unit volume (milligrams per m^3) at 3 stations on 8 dates in 1972.

average zooplankton weight as one moves shoreward, and proceeds seasonally. This trend is shown more clearly in Figure 11. The mean dry weight per individual zooplankter was highest (ca. 10 μg) offshore in spring. Offshore zooplankton weights decreased rapidly until July, and gradually thereafter, to a minimum of ca. 2 μg in October and November. The middle and inshore stations had smaller animals in June, and their weight further decreased to an August minimum (of ca. 1 μg/individual); thereafter there was a gradual increase so that by November the largest animals were found inshore (4 μg/individual), and the smallest were offshore. The explanation for this will be evident in the following paragraphs in which the seasonal dynamics of the individual species are considered, but may be summarized as follows. The offshore populations are dominated by copepods in spring; the increasing abundance of smaller Cladocera (chiefly *Bosmina longirostris*) reduces the average size as summer proceeds. At the middle and inshore stations, the smaller cladocerans appear earlier and dominate more completely by August. Thereafter, larger Cladocera like *Daphnia galeata mendotae*, *Daphnia retrocurva*, *Diaphanosoma leuchtenbergianum*, and *Holopedium gibberum* -- summer and fall species which are most abundant near shore -- cause an increase in mean zooplankter size.

Let us now consider the seasonal changes in abundance of the individual species at the three reference stations. This information is summarized in Figure 12, where species abundances are represented graphically in 13 abundance ranges. Note that each larger circle represents about twice as many animals as the next smaller-sized circle. The general overview of the information in Figure 12 shows that most copepods are perennial offshore but reduced in numbers inshore in summer, and that most cladocerans are rare in spring, appear first inshore, and reach their abundance maxima in summer and fall.

Immature copepods (nauplii, cyclopoid copepodids, and calanoid copepodids) were fairly perennial at all three stations, with annual minima in April and May.

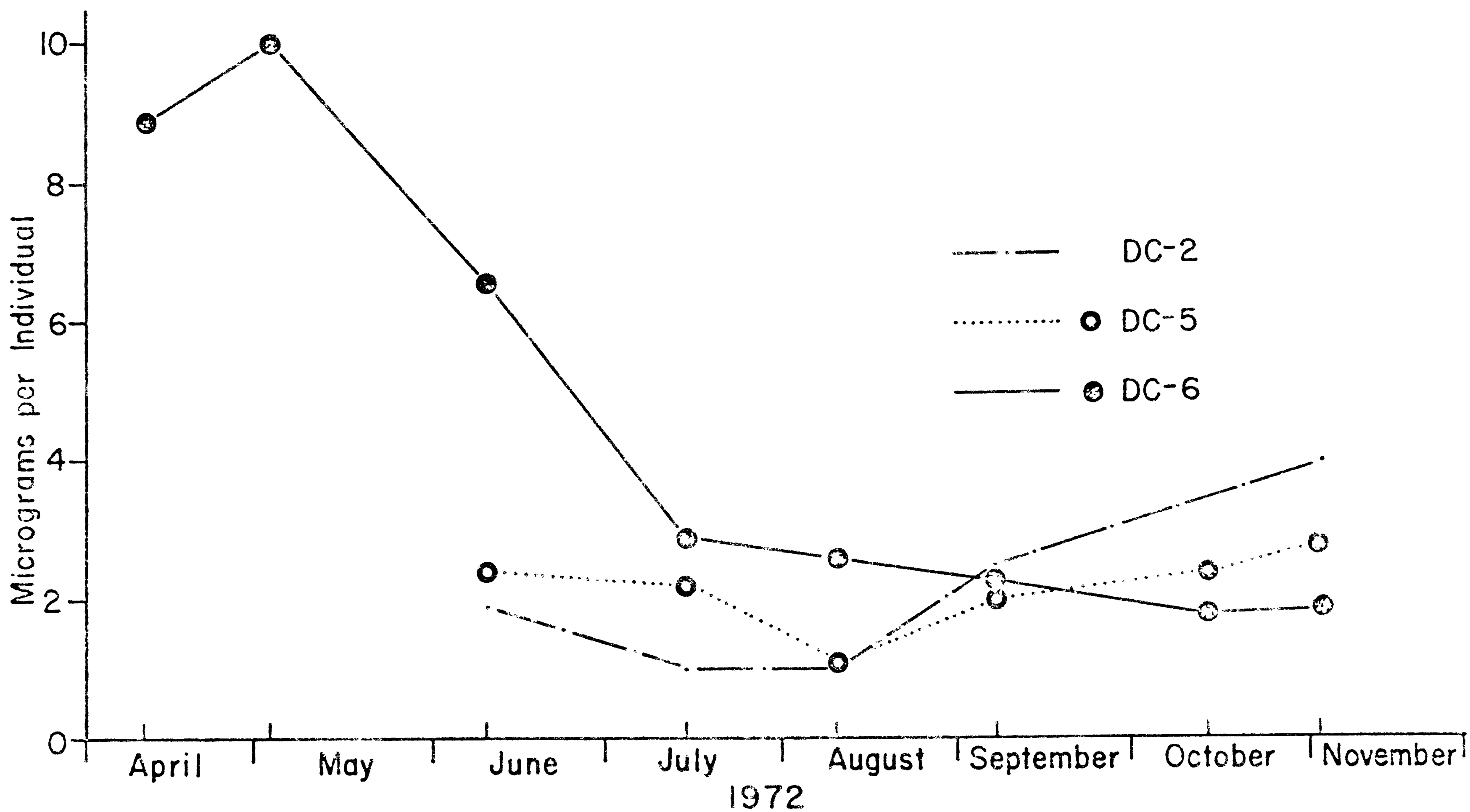

Figure 11. Zooplankton dry weight (micrograms per individual) at 3 stations on 8 dates in 1972.

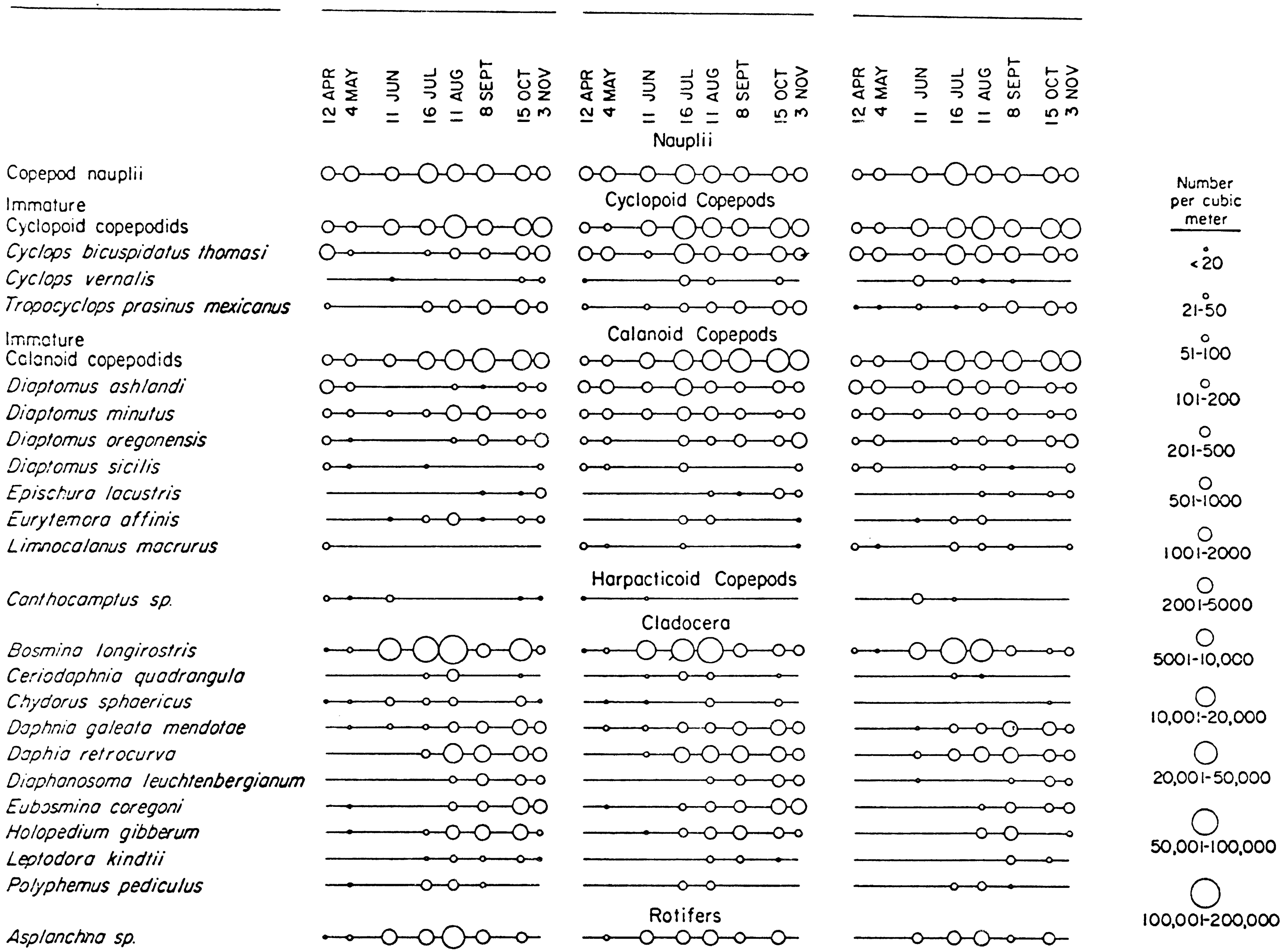

Figure 12. Zooplankton species abundances at 3 stations on 8 dates in 1972. Numbers per m^3 are expressed in 13 abundance ranges. Each larger circle represents approximately twice as many individuals as the next smaller circle.

The adults of the three dominant copepod species (*Cyclops bicuspidatus thomasi*, *Diaptomus ashlandi*, and *Diaptomus minutus*), were fairly abundant offshore at all seasons, but were definitely reduced in abundance inshore in summer. *Diaptomus ashlandi* is the first offshore dominant in spring. *Cyclops bicuspidatus thomasi* was most abundant inshore in April, but moved offshore as the season progressed.

Cyclops vernalis was a rare summer species which seldom occurred inshore. *Tropocyclops prasinus mexicanus*, the smallest cyclopoid copepod, also a relatively rare species, was most abundant from July to November; unlike the dominant copepod species, *Tropocyclops* was about equally abundant at the inshore, middle, and offshore stations.

Diaptomus oregonensis, a fairly uncommon species, was present offshore in every month except June. It was rare or absent inshore in summer, and reached its seasonal maximum (1,000 - 2,000 individuals/m^3) in all 3 zones in November. *Diaptomus sicilis* was rarer still, and was most abundant (100 - 200/m^3) in April, May, and November. *Epishura lacustris* was a late summer-fall species in all three zones. Its maximum abundance was 312/m^3. *Limnocalanus macrurus*, the largest copepod, was present at the inshore station only in April. It occurred occasionally at the middle and offshore stations from April to July. *Limnocalanus* is known to prefer cold water, and probably would have been more abundant if tows were made in deeper water in summer.

The only harpacticoid copepod we found, *Canthocamptus* sp., appeared in spring and fall at the inshore and middle stations, but in June was most abundant offshore (267/m^3). Its populations are probably derived from the littoral-benthic habitat, as are those of several of the cladoceran species.

Except for a few *Bosmina longirostris*, no Cladocera were found offshore in spring. The enormous develpment of the *Bosmina* population in June, July, and August has already been mentioned. *Bosmina* was very abundant then at all three sta-

tions, but the inshore maximum (178,000/m^3) was over three times as high as the maximum ever found at the middle or offshore stations (ca. 50,000/m^3). *Bosmina* accounted for 30 - 40% of the total zooplankton assemblage at the offshore station in these months; at the middle station it accounted for from 33 - 56% of the total; and at the inshore station, it completely dominated the fauna, accounting for 63 - 72% of the animals found.

The other bosminid species, *Eubosmina coregoni*, was present in sizeable numbers only between August and November. Its maximum (ca. 9,000/m^3) occurred inshore in October. *Ceriodaphnia quadrangula* was a summer species only rarely found offshore. At the inshore station in August it achieved its seasonal maximum of 579/m^3. *Chydorus sphaericus* occurred sporadically at the inshore and middle stations, but was only found offshore once.

Daphnia galeata mendotae appeared inshore in May but reached its seasonal maximum (3,000/m^3) in October. It appeared later offshore and was never as abundant there. *Daphnia retrocurva* was also a summer and fall species most abundant inshore. It accounted for over 12,000 individuals/m^3 at the inshore station in August. *Diaphanosoma leuchtenbergianum* had a similar seasonal distribution, but was much more rare, never exceeding 700/m^3.

Holopedium gibberum, also an inshore-summer species, only exceeded 3,000/m^3 once, in September. *Leptodora kindtii* was very rare, but occurred most often inshore, and in late summer and fall. *Polyphemus pediculus* occurred on a few dates in summer; it was most abundant inshore, but never exceeded 400/m^3.

The only rotifer we enumerated, *Asplanchna* sp., was present inshore during every month except November, and was usually present (although rarer) offshore as well. Its maximum abundance was 22,000/m^3 at the inshore station in August.

Having considered the seasonal succession of species at these reference stations, it is appropriate to consider how consistently this pattern is repeated

in other parts of the sampling grid.

The Spatial Distribution of the Major Components of the Fauna on the Eight Survey Dates

1. The full survey of 12 April. The total zooplankton numbers at each station are shown in Figure 13. Most of the stations with over 5,000/m^3 were located between the 10 and 20 meter depth contours. A few stations (SDC-7-1, SDC-7-4, SDC-2-2, SDC-.5-2, DC-1, NDC-1-2, NDC-2-1, NDC-7-4) had less than 2,000/m^3. Most of these were close to shore. The qualitative composition of the fauna at these stations is summarized in Figures 14 and 15. The offshore stations had over 40% adult *Diaptomus* (mostly *D. ashlandi*); a few stations close to shore (circled in Figure 10) also had over 40% *Diaptomus*. These stations were concentrated in two patches, one including 3 stations on the SDC-1 and SDC-2 lines, the other including 4 stations between the NDC-.5 and NDC-4 lines. Most stations had 20 - 30% *Cyclops* (essentially all *C. bicuspidatus thomasi*). A few patches (circled in Figure 15) of over 40% *Cyclops* occurred. The largest of these was near the plant, between 15 and 20 meters depth.

2. The reduced survey of 4 May. In May there was little variation in total numbers between the 8 stations sampled, most stations having 4,000 - 5,000 individuals/m^3. However, at SDC-.5-2, only 1,600/m^3 were found (Figure 16).

3. The reduced survey of 11 June. In June all stations except the three closest to shore had 20,000 - 30,000 individuals/m^3; the three exceptions (SDC-.5-2, DC-1, NDC-.5-2) had only 5,000 - 9,000/m^3 (Figure 17). The summer dominance of *Bosmina longirostris* was already established in June (Figure 18); of the five high abundance stations, only the most offshore was dominated by copepods in June. The other four had over 50% *Bosmina*.

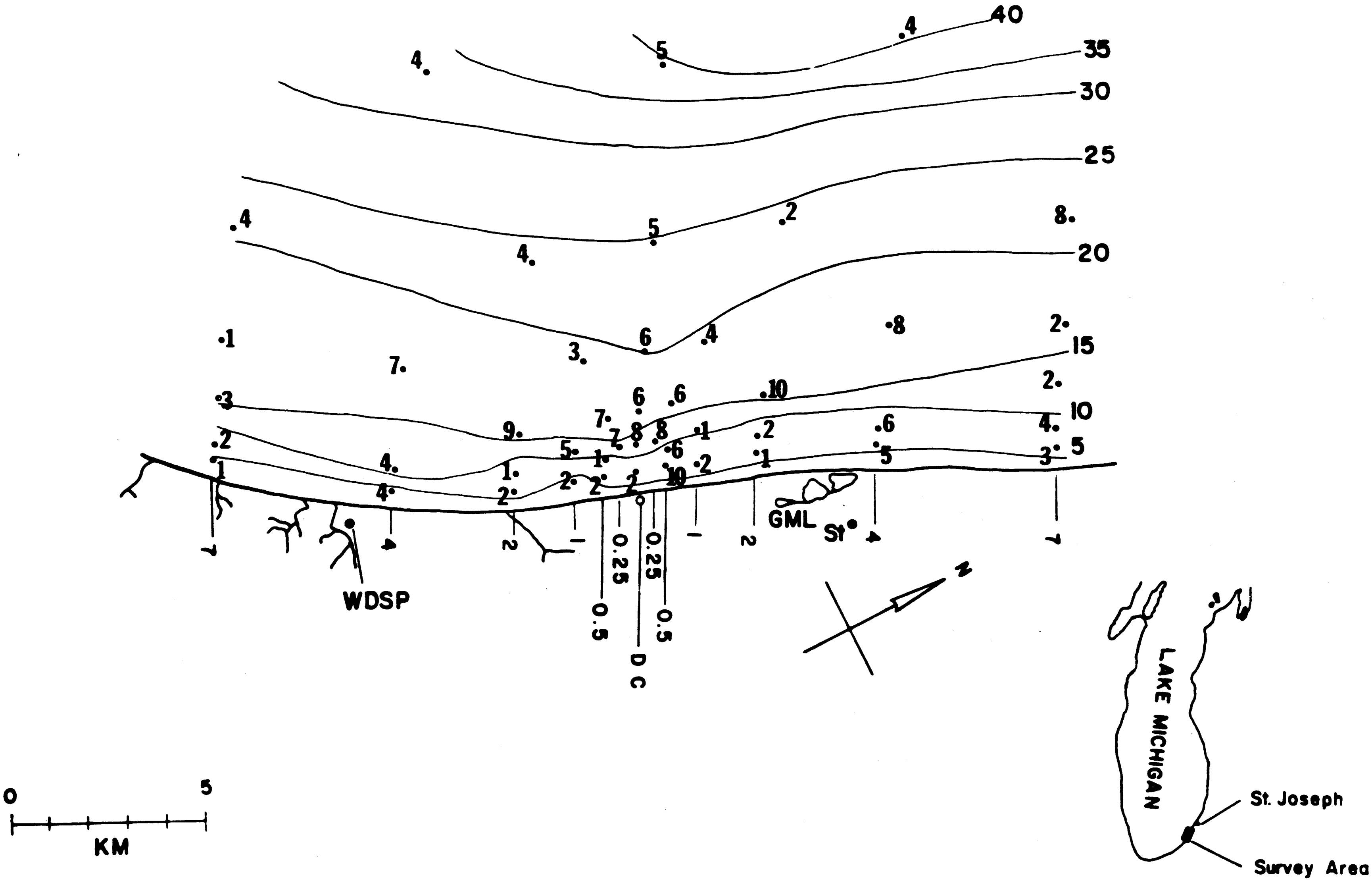

Figure 13. The spatial distribution of total zooplankton counts (individuals per liter) at 46 stations on 12 April 1972.

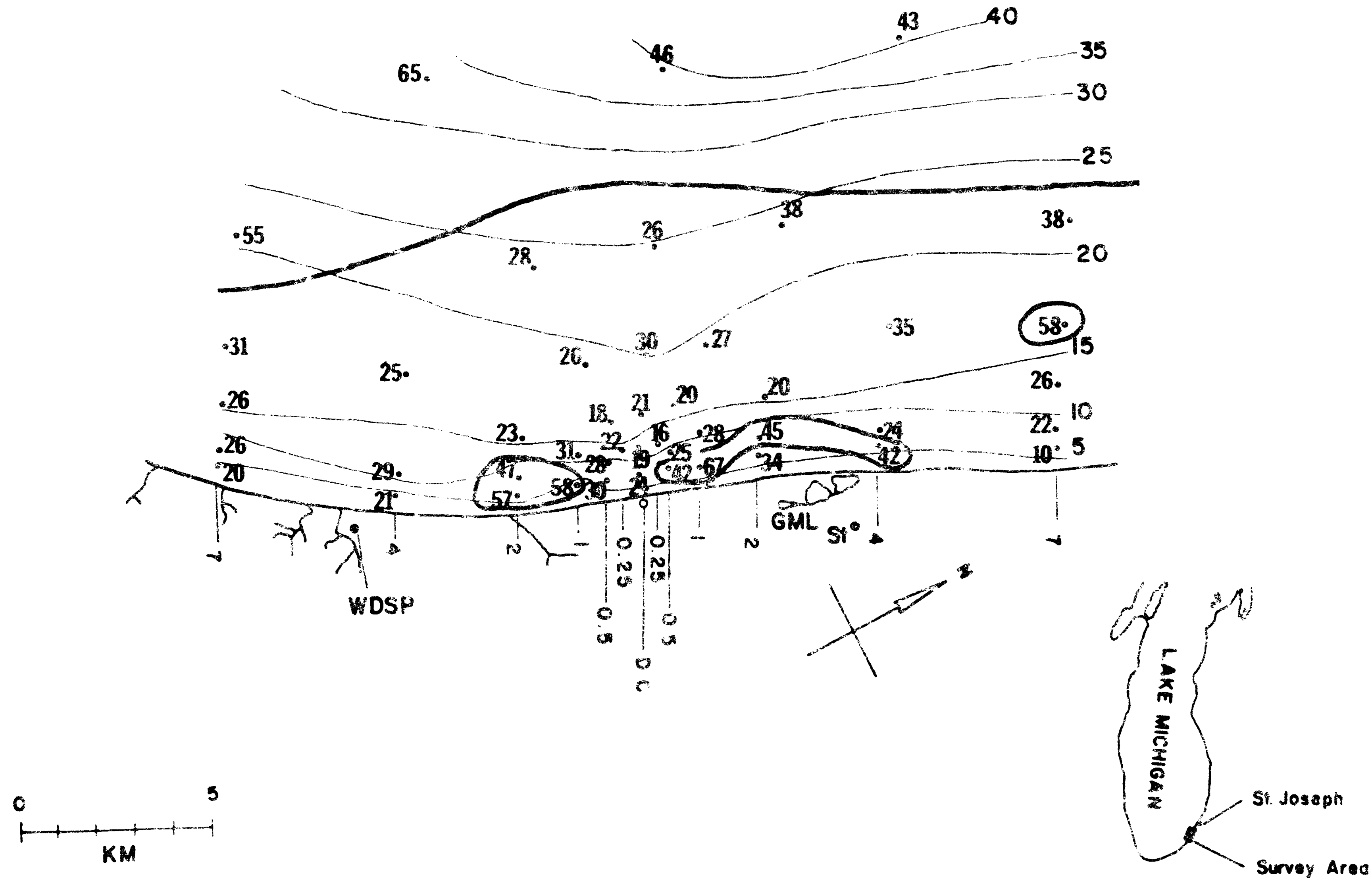

Figure 14. The spatial distribution of relative *Diaptomus* abundance (% of total zooplankton assemblage) at 46 stations sampled on 12 April 1972. Heavy lines enclose stations over 40%.

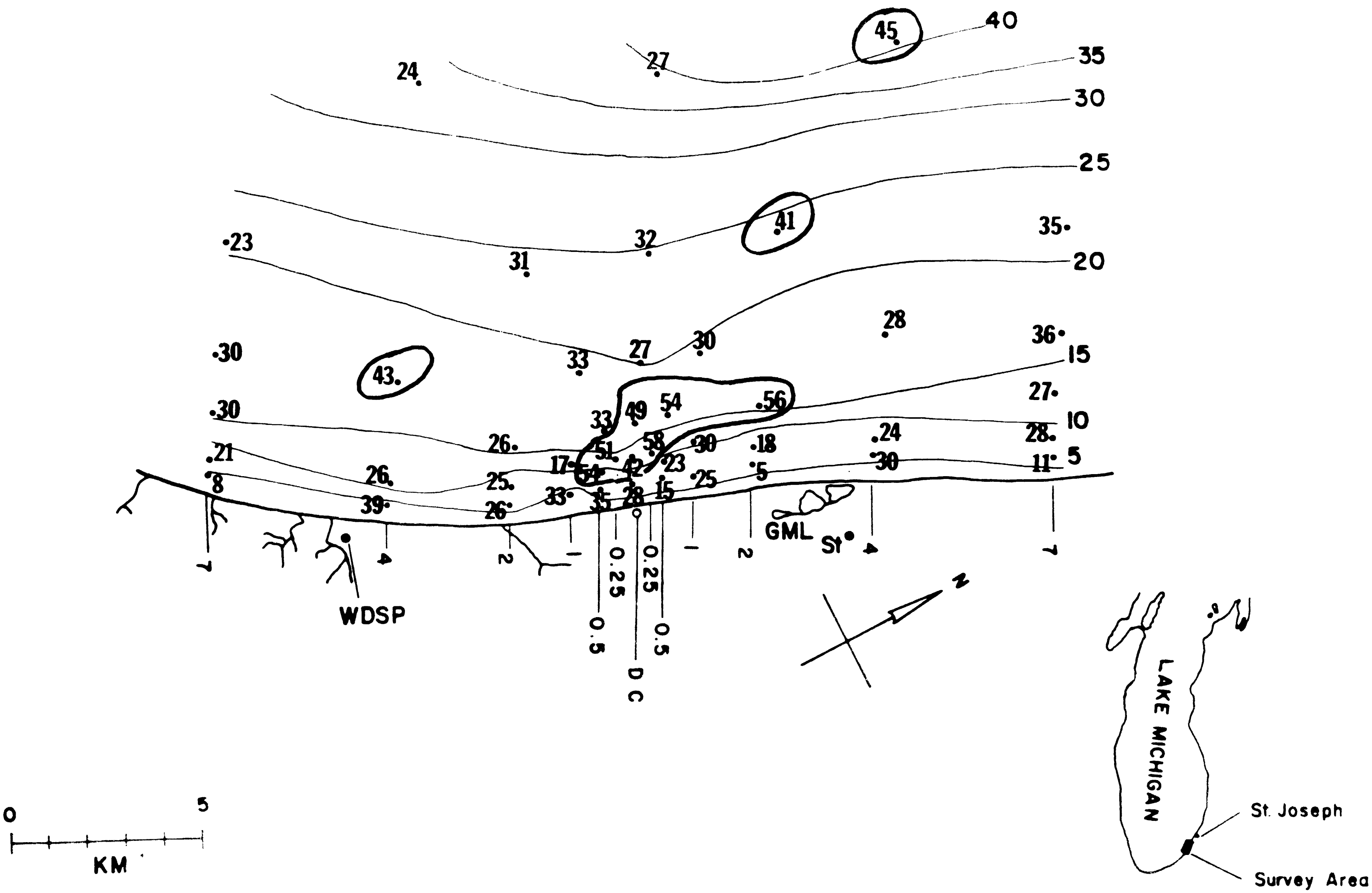

Figure 15. The spatial distribution of relative *Cyclops* abundance (% of total zooplankton assemblage) at 46 stations sampled on 12 April 1972. Heavy lines enclose stations over 40%.

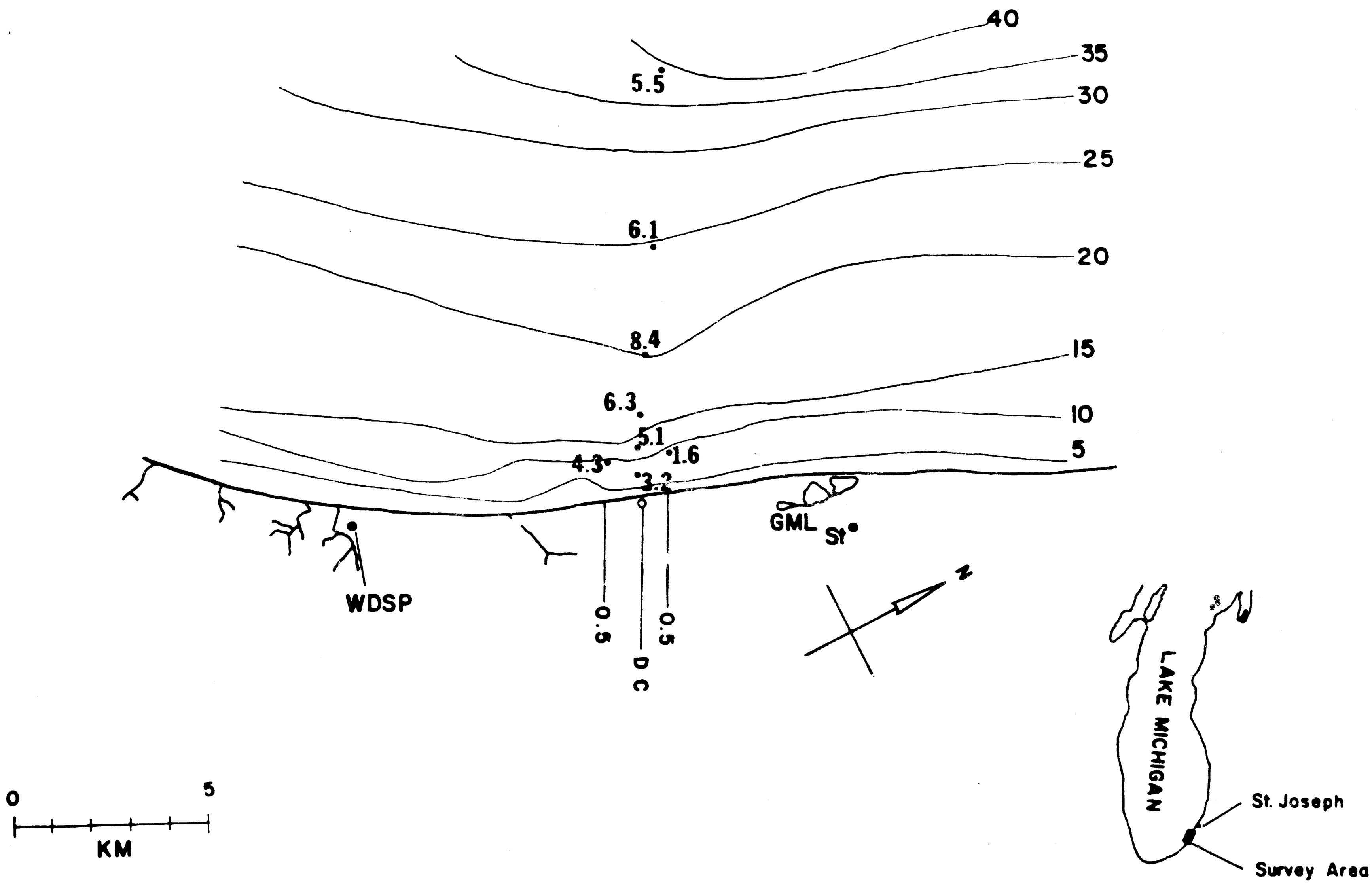

Figure 16. The spatial distribution of total zooplankton counts (individuals per liter) at 8 stations on 4 May 1972.

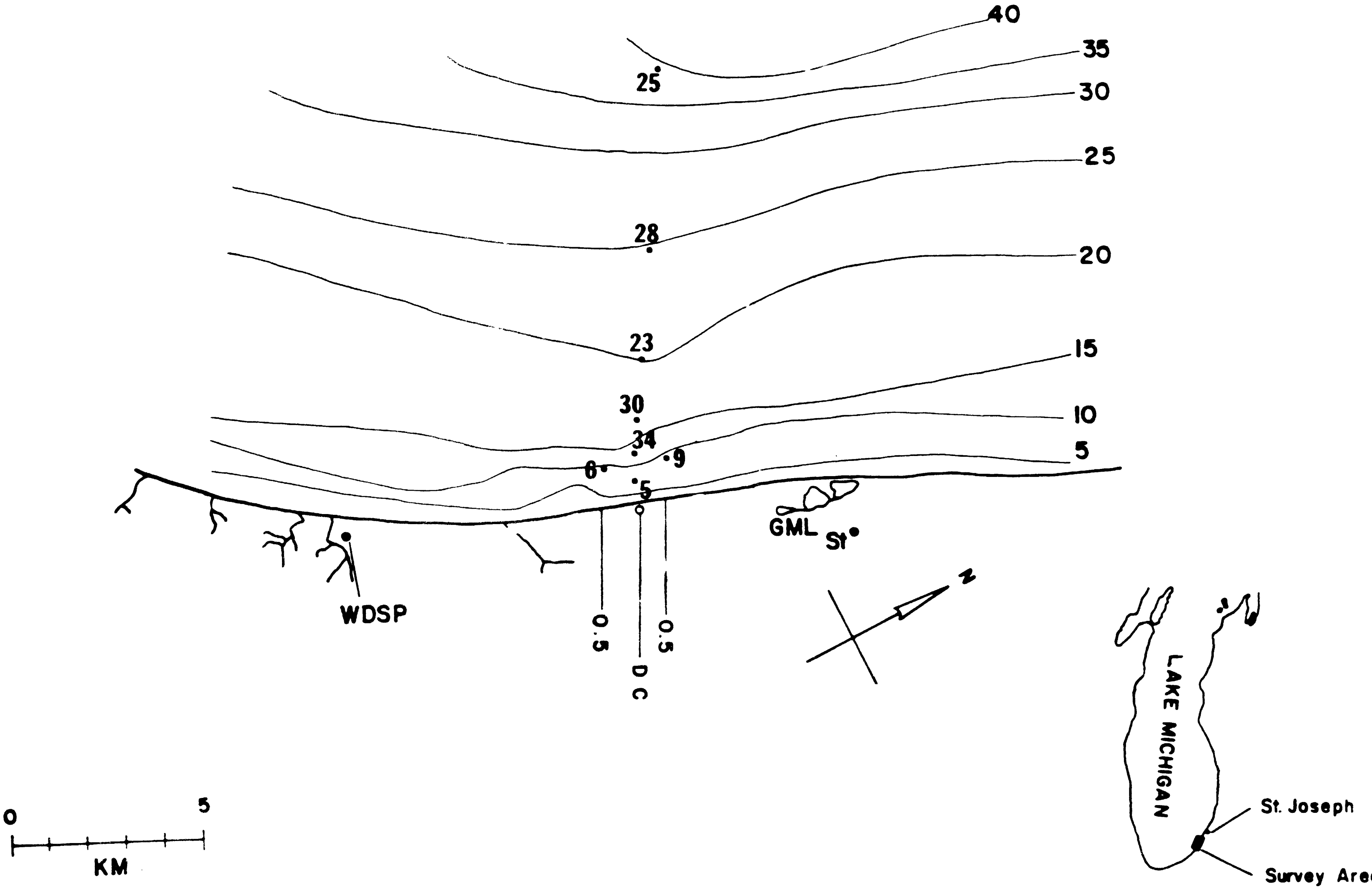

Figure 17. The spatial distribution of total zooplankton counts (individuals per liter) at 8 stations on 11 June 1972.

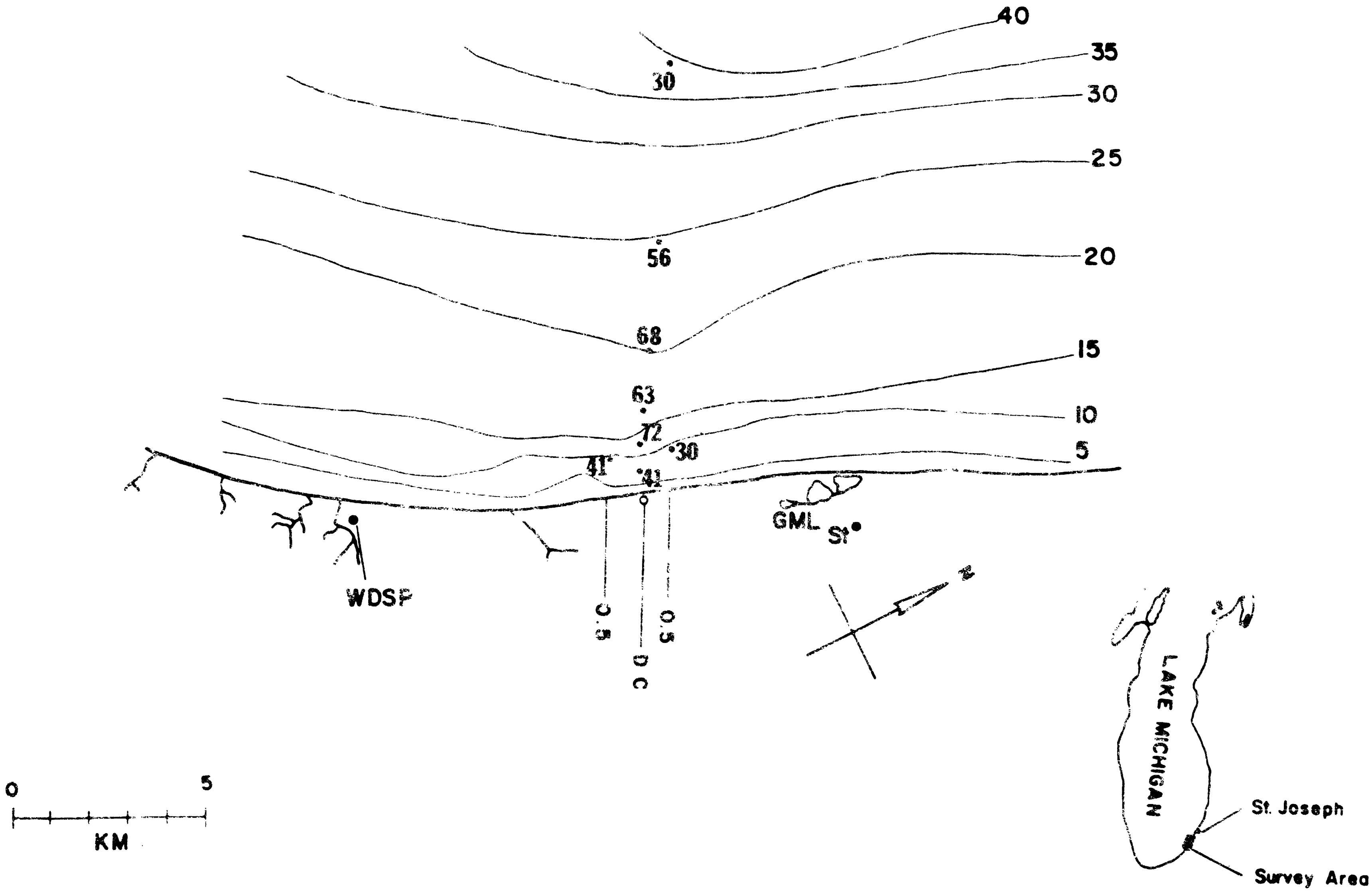

Figure 18. The spatial distribution of relative *Bosmina* abundance (% of total zooplankton assemblage) at 8 stations sampled on 11 June 1972.

4. <u>The full survey of 16 July</u>. In July most of the near-shore stations had between 30,000 and 80,000 individuals/m^3, and the offshore stations had over 100,000/m^3 (Figure 19). The line separating these zones roughly corresponded to the 15-meter depth contour. Adult *Diaptomus* and *Cyclops* were essentially absent in the near-shore zone (Figures 20 and 21). This zone was heavily dominated by *Bosmina*, which accounted for over 60% of the fauna at every station, and occasionally for as much as 80 - 87% (Figure 22).

5. <u>The reduced survey of 11 August</u>. Unlike June and July, the highest zooplankton numbers were found near shore in August (Figure 23). There was, however, large variation between samples collected close together. Station SDC-.5-2 had 129,000/m^3; station DC-2, only about 1/2 mile away, had 281,000/m^3; and station NDC-.5-2, equally close to DC-2, had the truly incredible total of 584,000/m^3, the highest count we or anyone else has reported from Lake Michigan. There were fewer zooplankton farther offshore in August; the total at DC-6 was 81,000/m^3. That the near-shore assemblage continued to be dominated by *Bosmina* is shown in Figure 24. All of the near-shore stations had over 60% *Bosmina*. 77% of the animals at station NDC-.5-2 (i.e., 448,000 individuals/m^3) were this one species. The offshore stations had relatively fewer *Bosmina*; there, immature copepods accounted for the largest part of the total fauna.

6. <u>The reduced survey of 8 September</u>. In September, the total zooplankton numbers were much less than in August, most stations having 40,000 - 50,000 individuals/m^3. Exceptions were DC-4 (97,000/m^3) and NDC-.5-2 (13,000/m^3) (Figure 25). The *Bosmina* population had crashed; only 4 - 6% of the fauna was *Bosmina* inshore, and 0 - 2% offshore (Figure 26). Immature cyclopoid copepodids made up 20% of the fauna offshore, but only 2 - 5% inshore (Figure 27). Immature calanoid copepodids were more important in September, everywhere accounting for 30 - 40% of

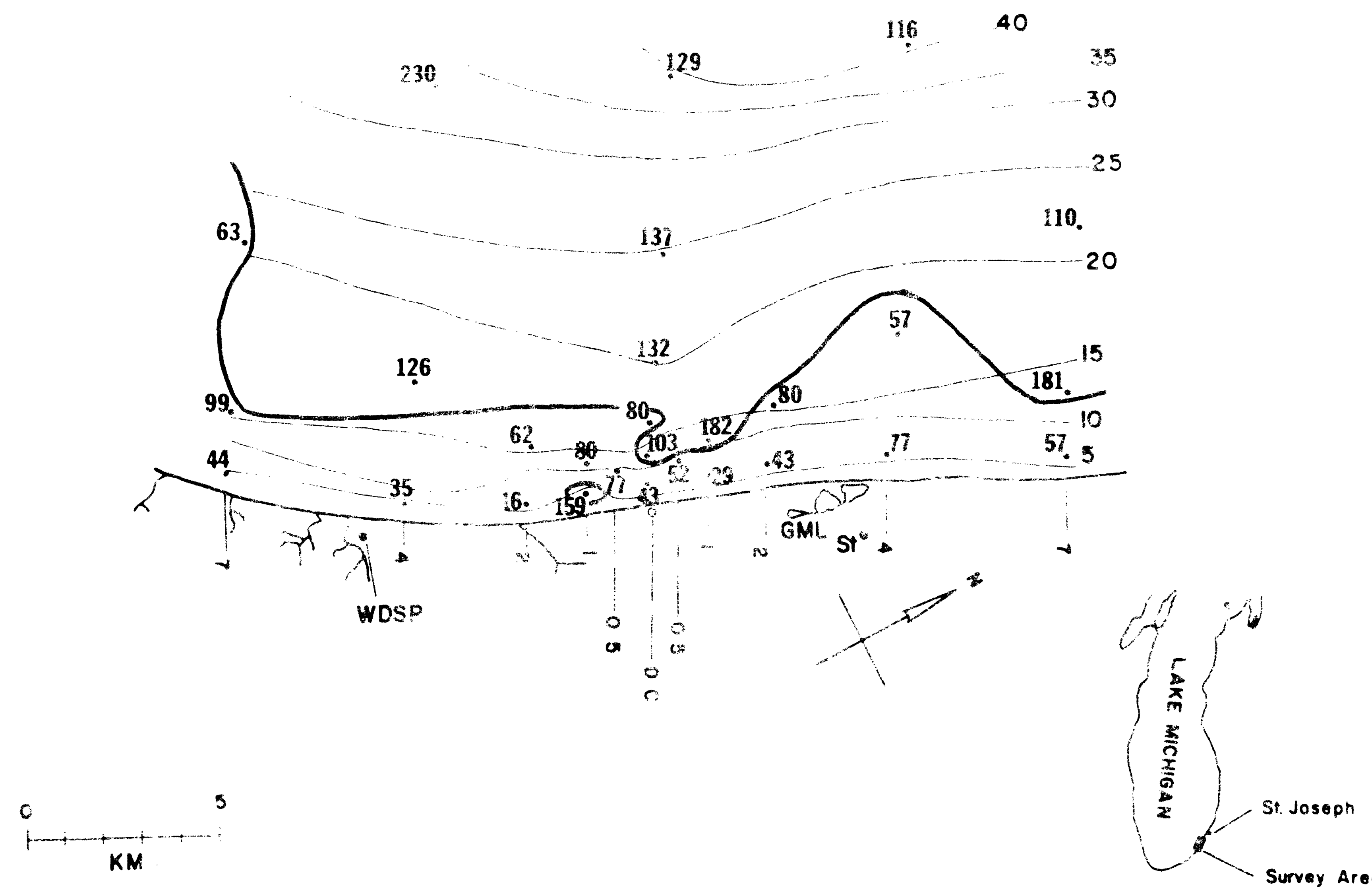

Figure 19. The spatial distribution of total zooplankton counts (individuals per liter) at 29 stations on 16 July 1972. Heavy lines enclose stations over 100 individuals per liter.

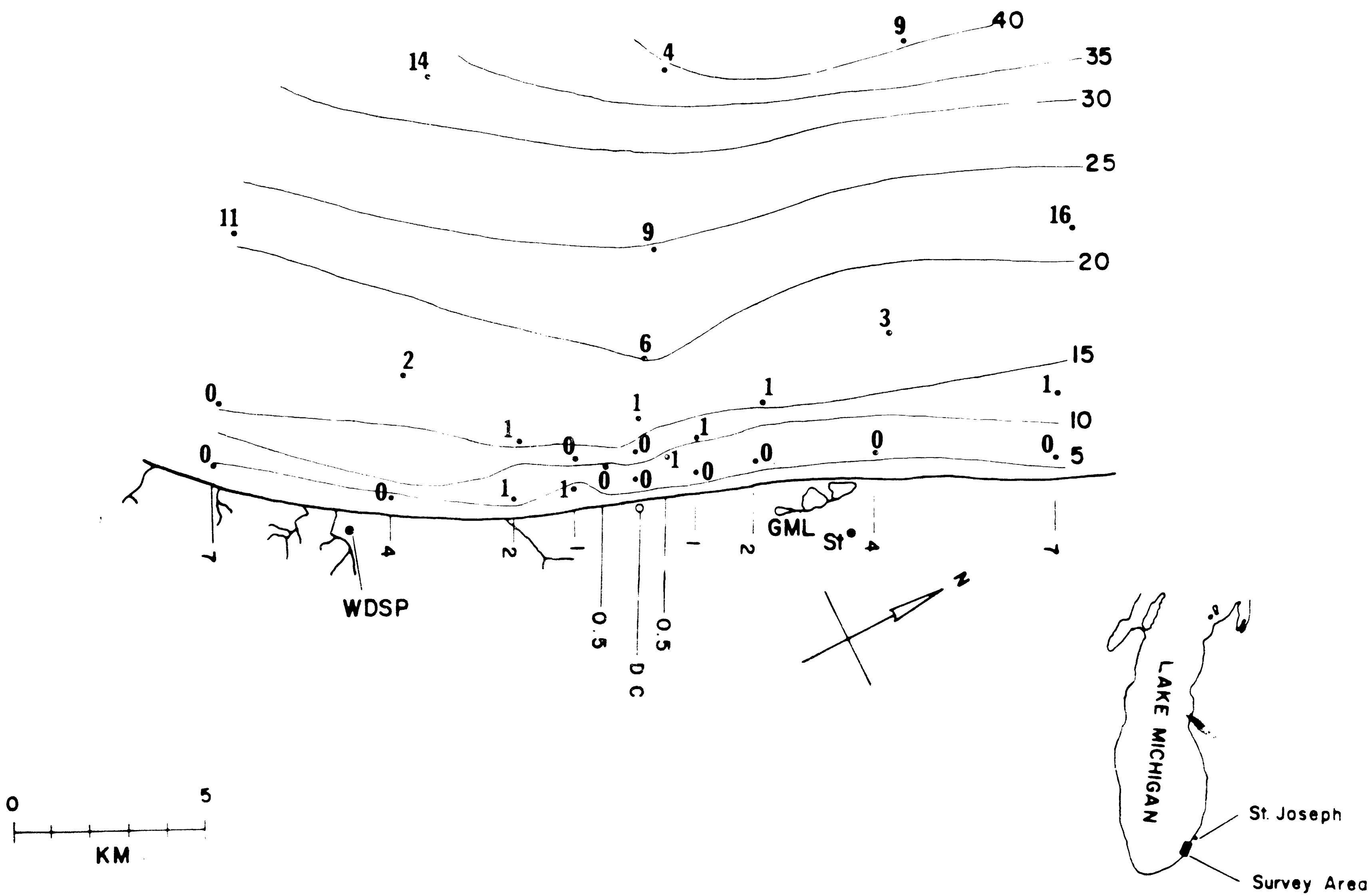

Figure 20. The spatial distribution of relative *Diaptomus* abundance (% of total zooplankton assemblage) at 29 stations on 16 July 1972.

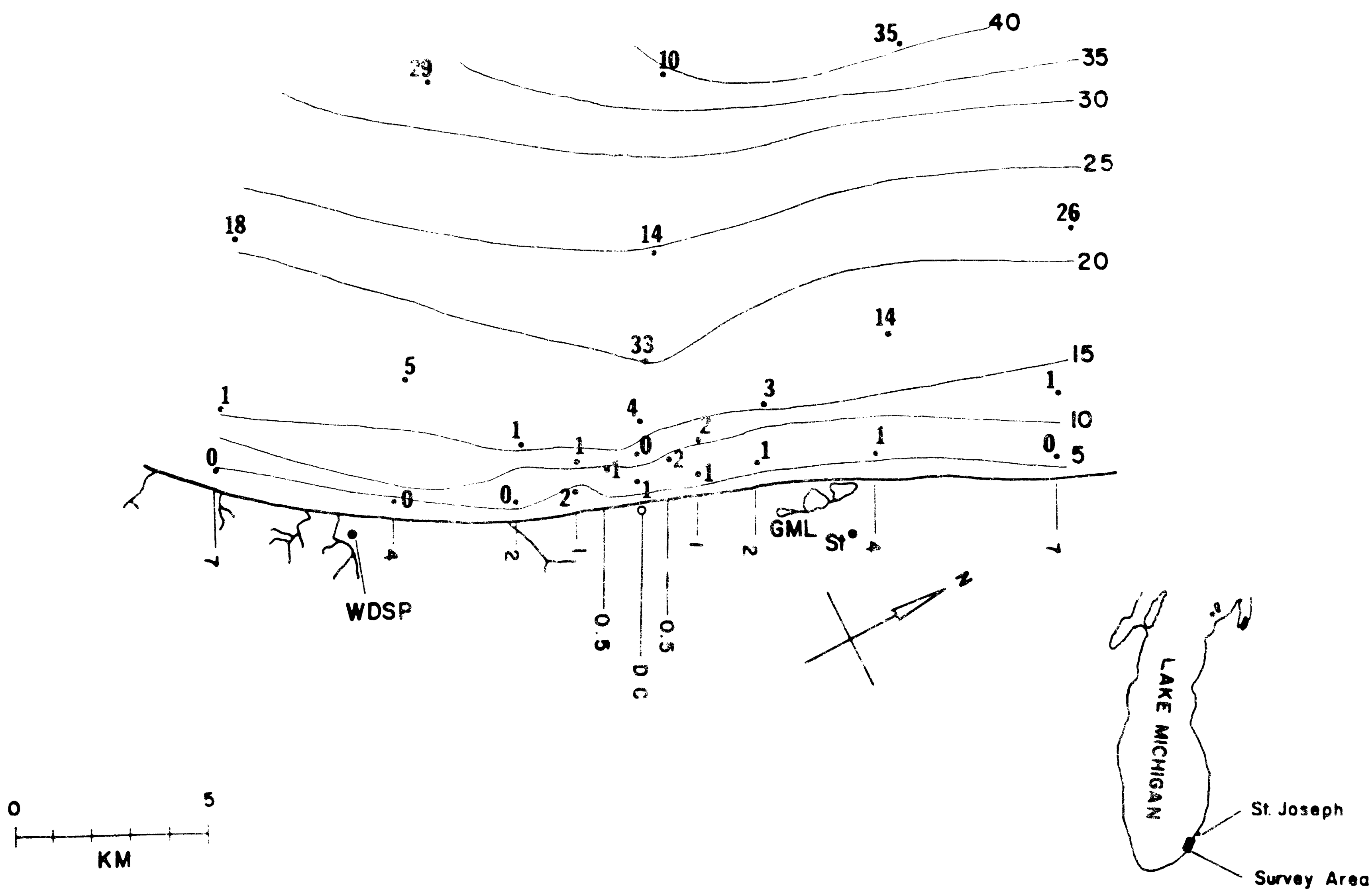

Figure 21. The spatial distribution of relative *Cyclops* abundance (% of total zooplankton assemblage) at 29 stations sampled on 16 July 1972.

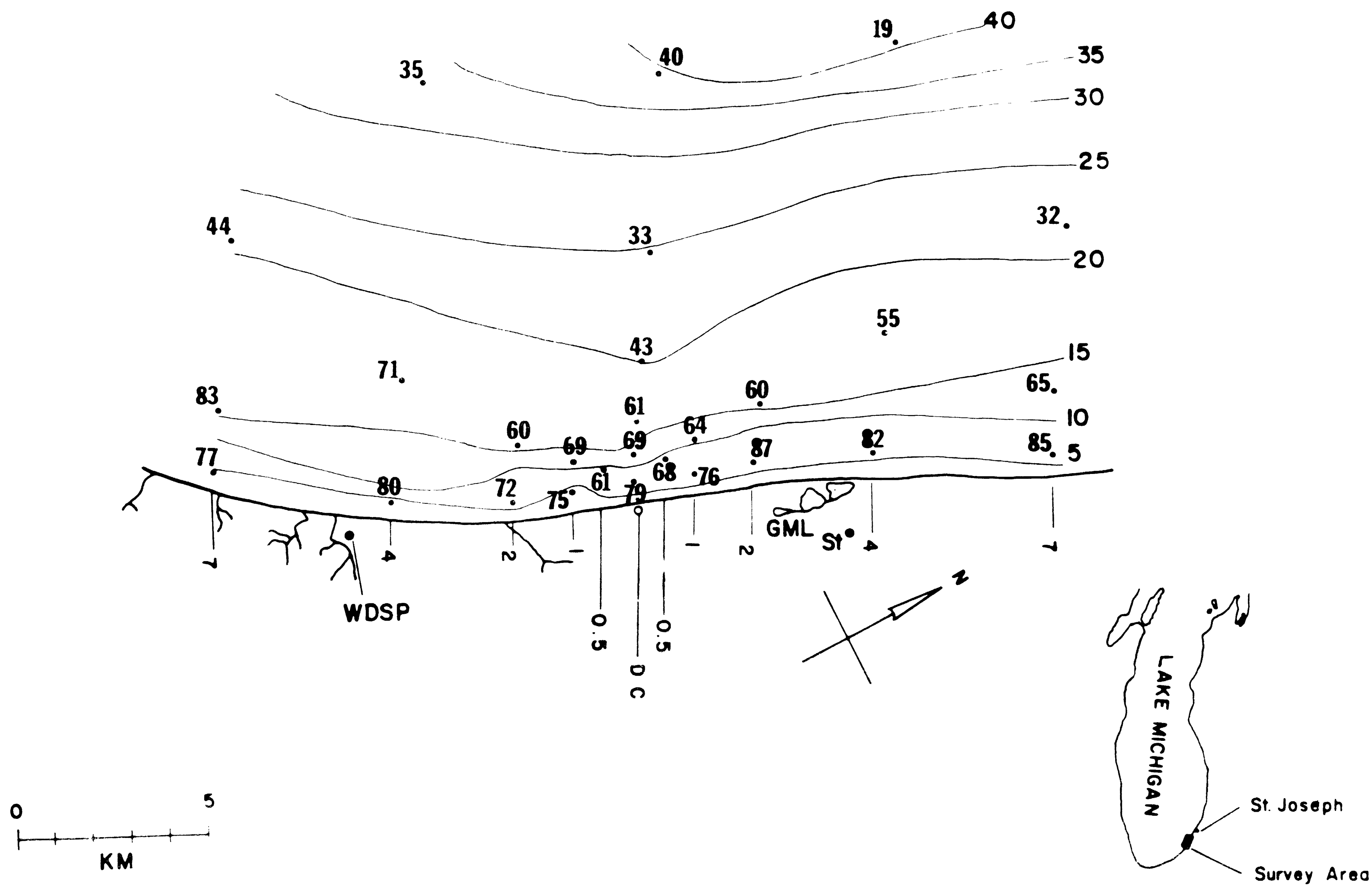

Figure 22. The spatial distribution of relative *Bosmina* abundance (% of total zooplankton assemblage) at 29 stations sampled on 16 July 1972.

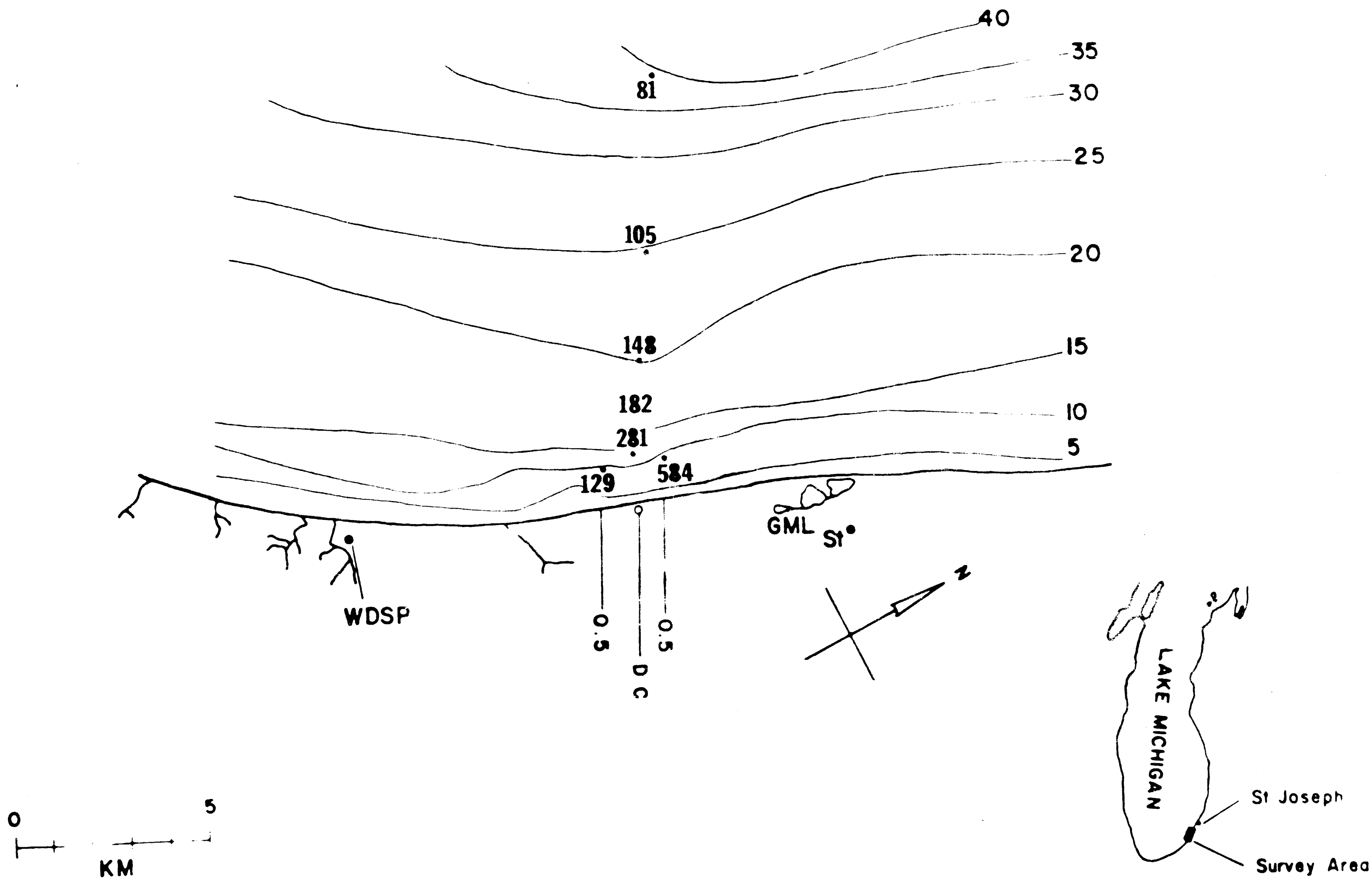

Figure 23. The spatial distribution of total zooplankton counts (individuals per liter) at 7 stations on 11 August 1972.

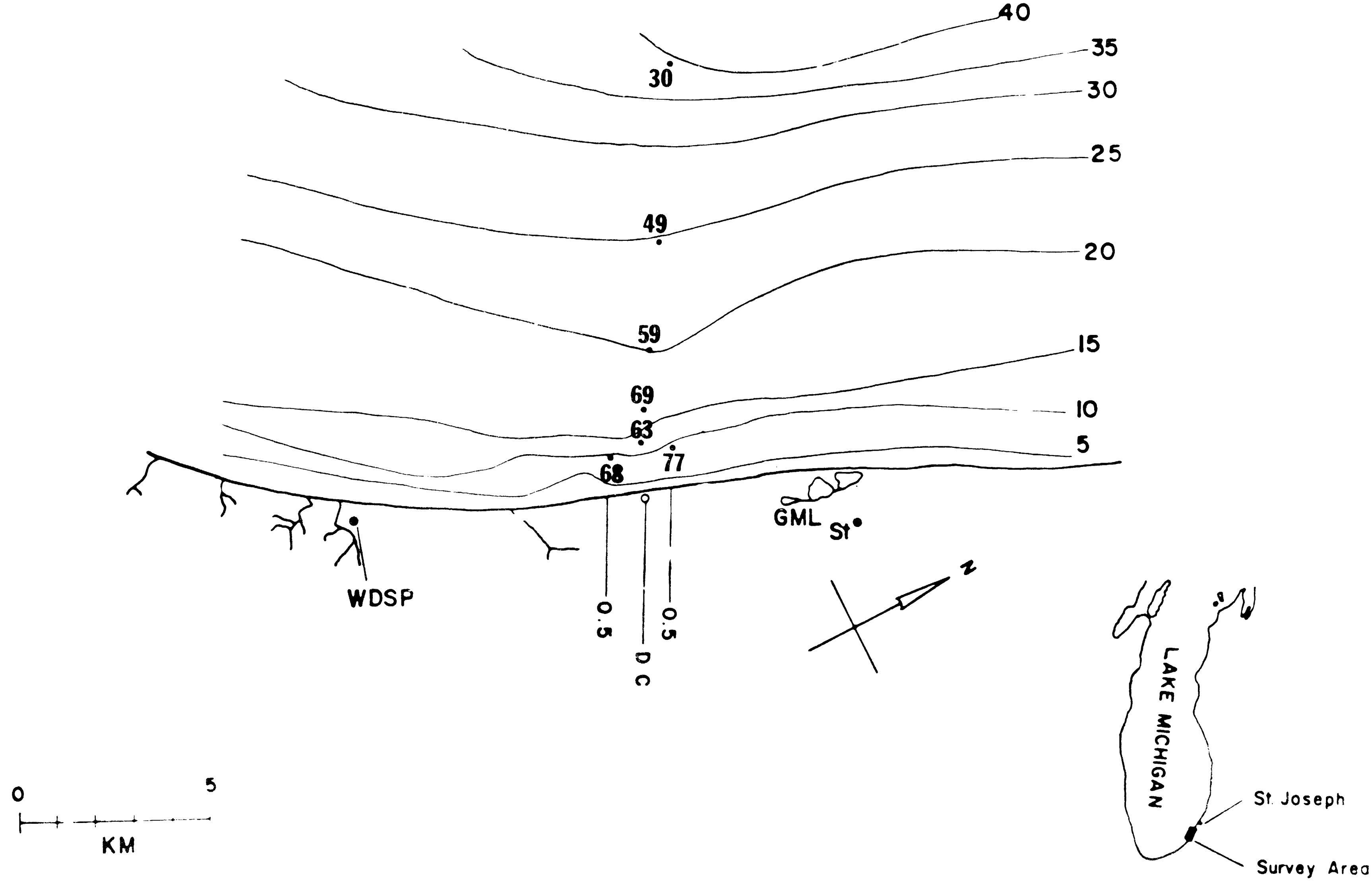

Figure 24. The spatial distribution of relative *Bosmina* abundance (% of total zooplankton assemblage) at 7 stations sampled on 11 August 1972.

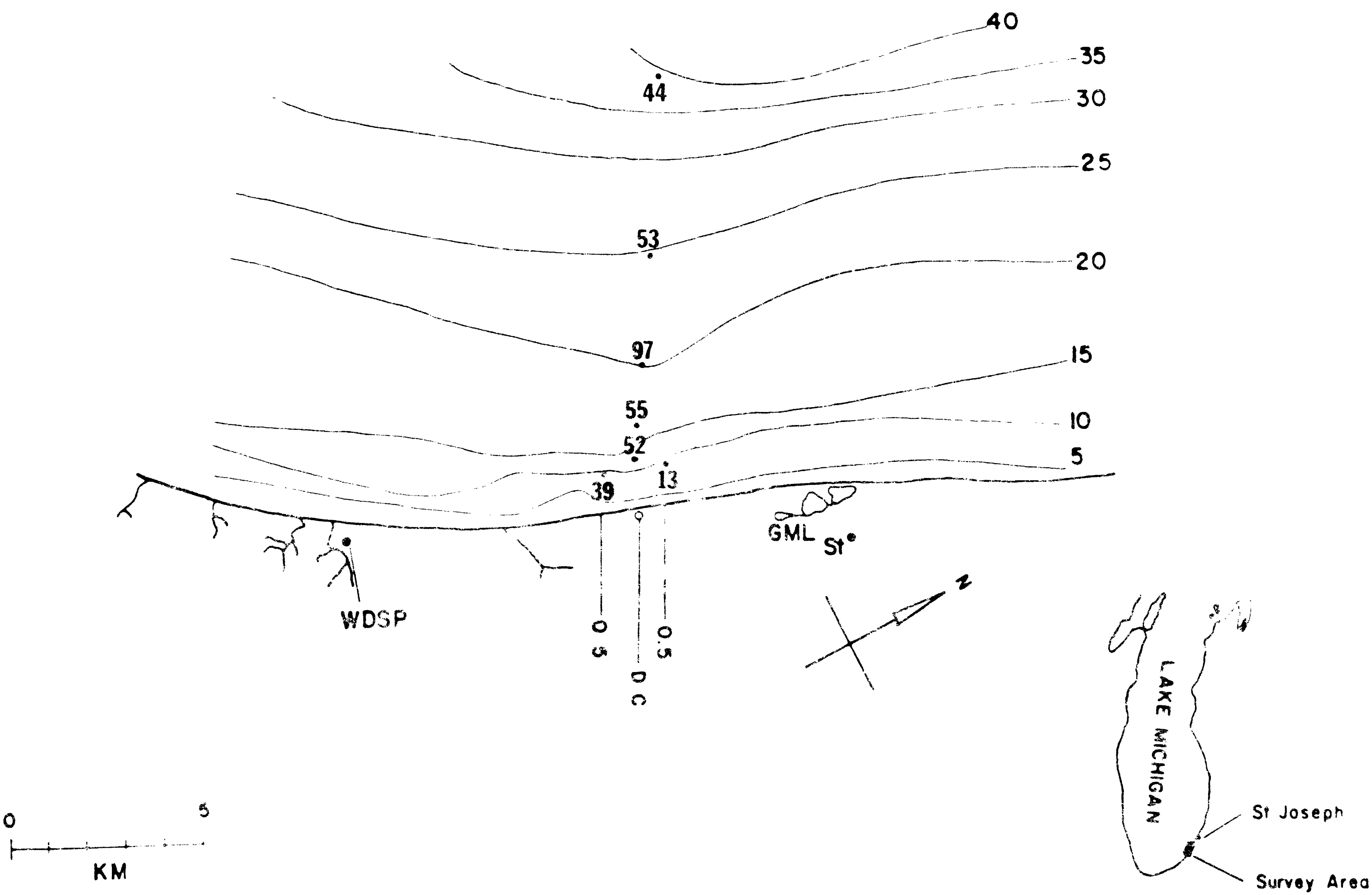

Figure 25. The spatial distribution of total zooplankton counts (individuals per liter) at 7 stations on 8 September 1972.

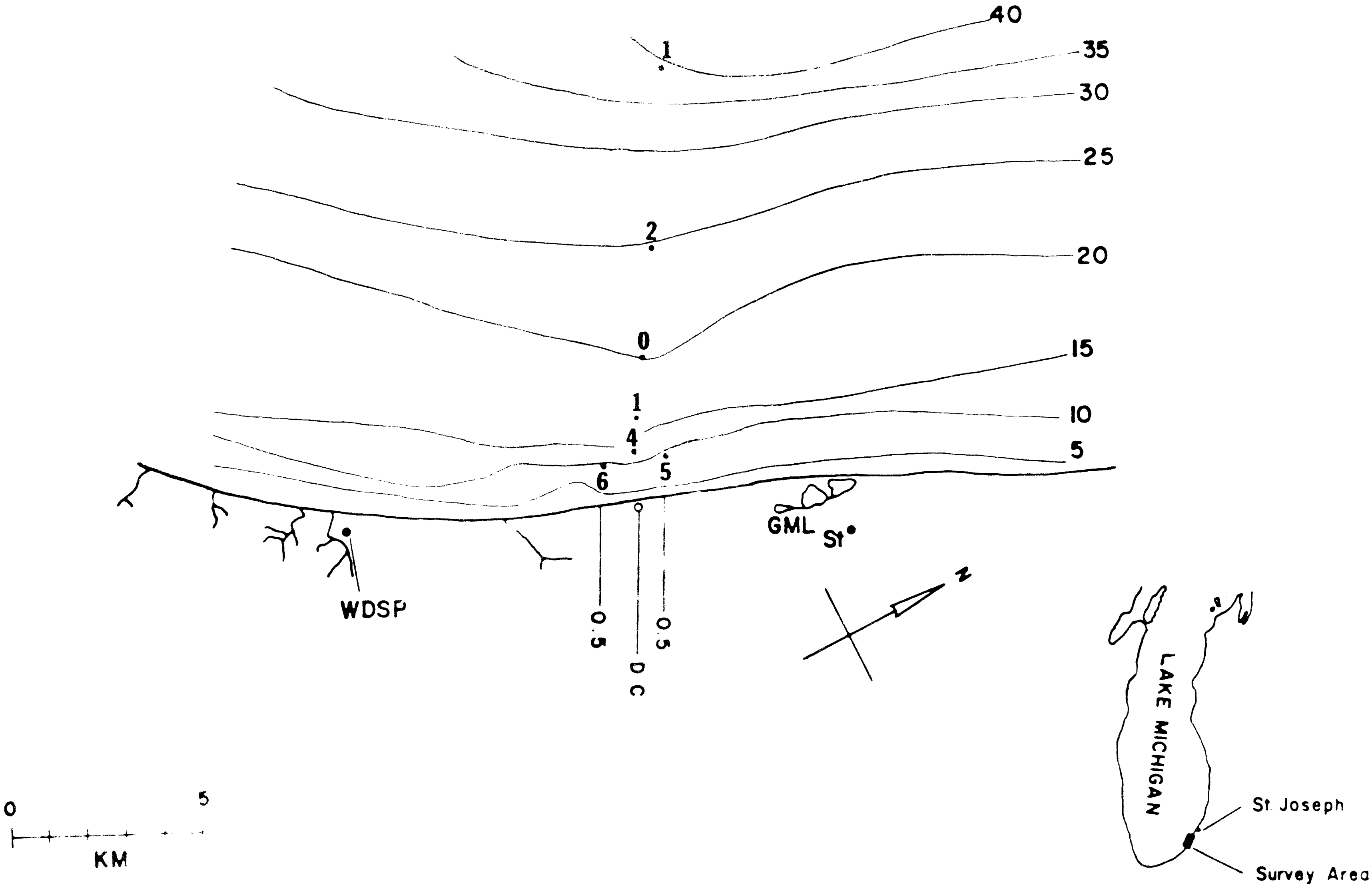

Figure 26. The spatial distribution of relative *Bosmina* abundance (% of total zooplankton assemblage) at 7 stations on 8 September 1972.

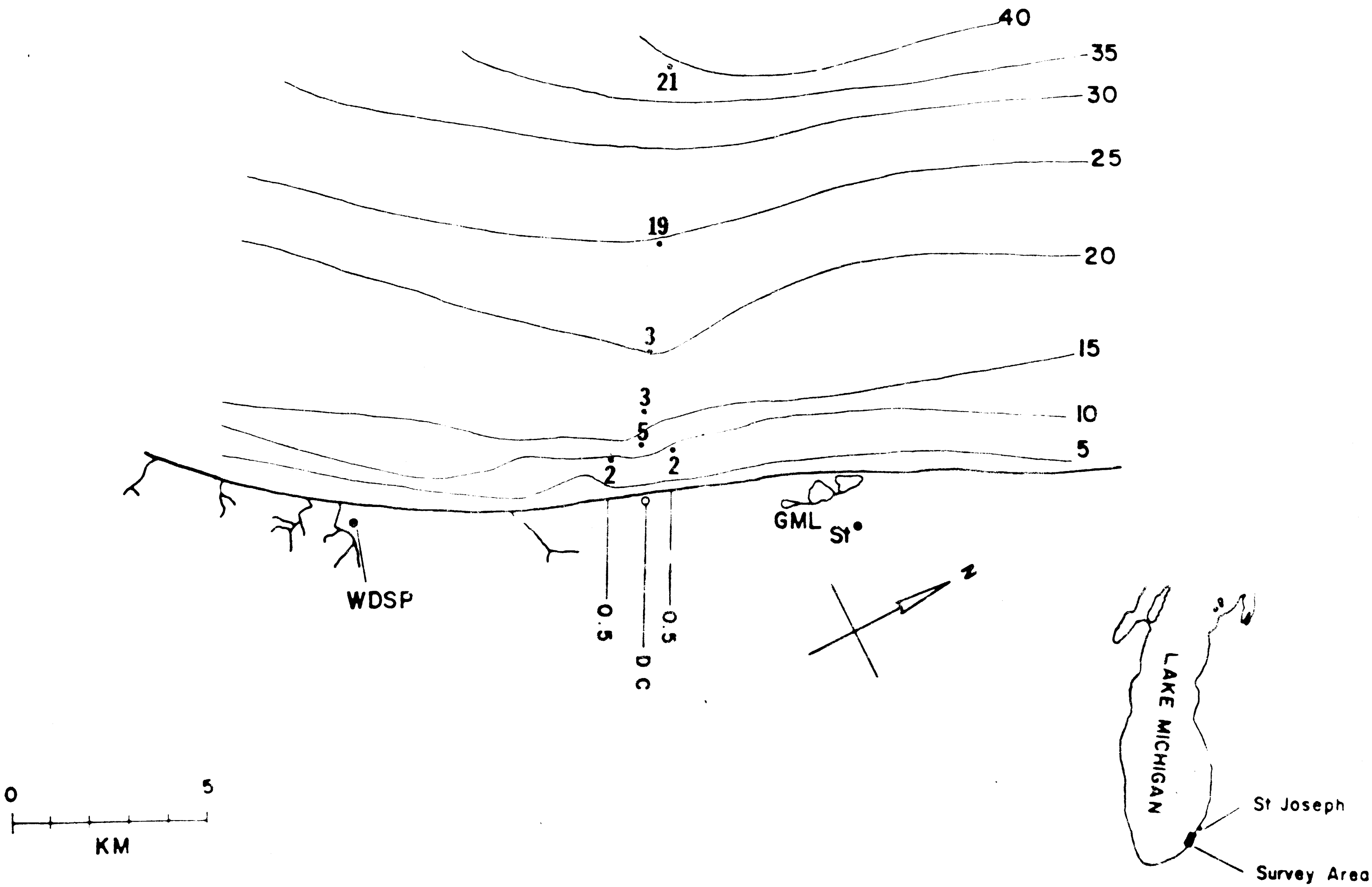

Figure 27. The spatial distribution of relative immature cyclopoid copepodids abundance (% of total zooplankton assemblage) at 7 stations sampled on 8 September 1972.

of the fauna (Figure 28). *Daphnia* became a significant part of the fauna in September, accounting for about 20% of the fauna at most stations, and nearly half at station SDC-.5-2 (Figure 29).

7. The full survey of 15 October. In October the zooplankton populations showed great variability. Nine stations scattered through the study area had over 50,000 individuals/m^3; abundances at the other 17 stations ranged from 17,000 - 50,000/m^3 (Figure 30). Immature calanoid copepodids were an important constituent of the offshore fauna in October (40 - 50%), but close to shore made up less than 20% of the fauna (Figure 31). The second *Bosmina* pulse, mentioned earlier, was confined to the near-shore area (Figure 32), unlike the *Bosmina* distributions in June - August.

8. The short survey of 3 November. In November total zooplankton abundances were about 20,000 - 30,000/m^3 at all seven stations (Figure 33). Immature calanoid copepodids were important constituents of the fauna, accounting for 25 - 45% at all stations (Figure 34). Immature cyclopoid copepodids accounted for about a third of the fauna offshore, but less than 20% near shore (Figure 35). *Eubosmina coregoni* and *Daphnia* spp. were both important inshore (Figures 36 and 37).

Summary of Biomass Information From All Stations

The biomass information from all stations is summarized in Figures 38 and 39. The mean values are plotted, along with the standard deviations between stations. The number of stations averaged for each date is given in parentheses. The rather large standard deviations shown in Figures 38 and 39 resulted from combining both inshore and offshore stations. Interpretation of this data has been given in conjunction with stations DC-6, DC-5, and DC-2 above, and need not be

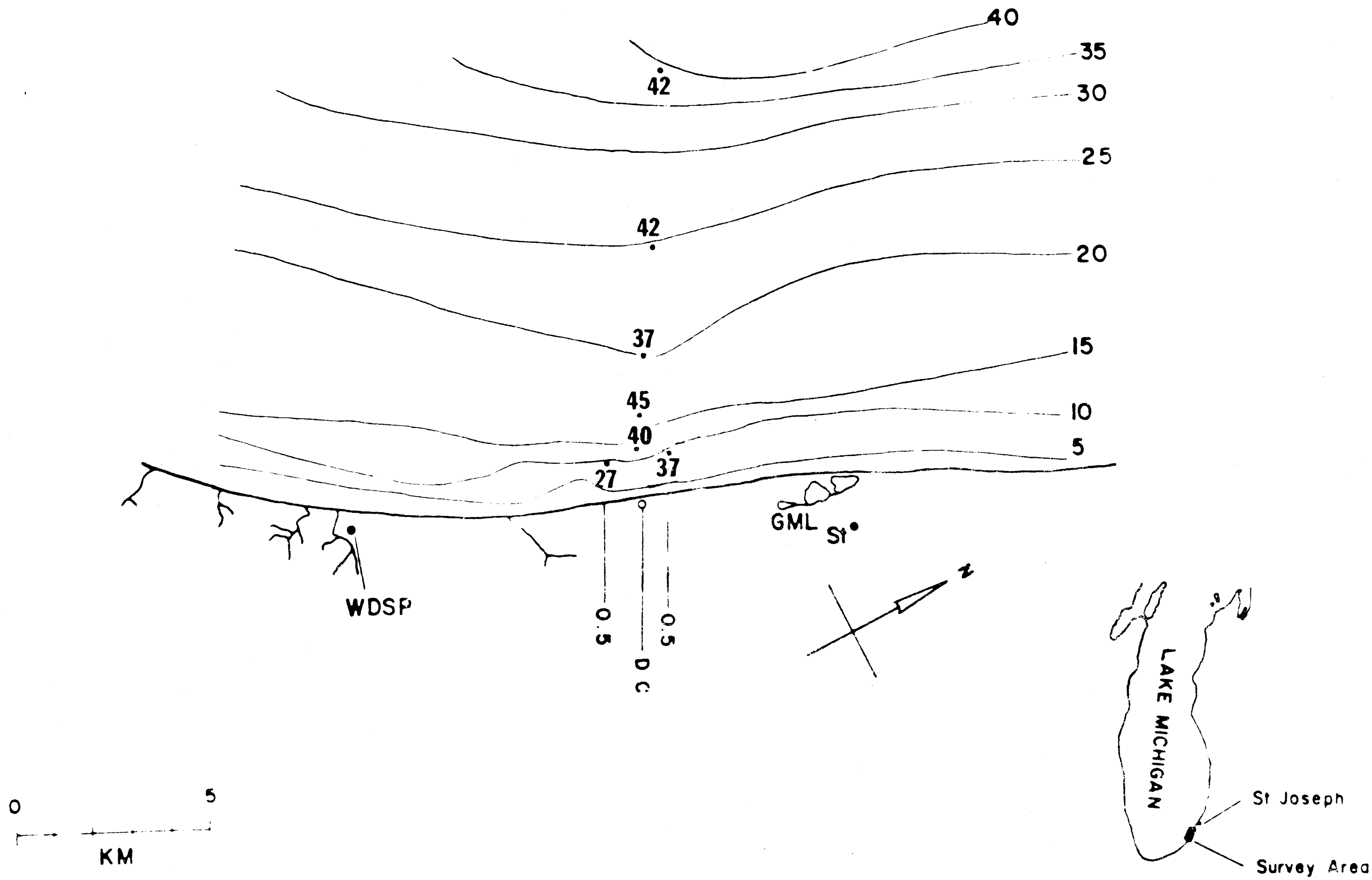

Figure 28. The spatial distribution of relative immature calanoid copepodids abundance (% of total zooplankton assemblage) at 7 stations sampled on 8 September 1972.

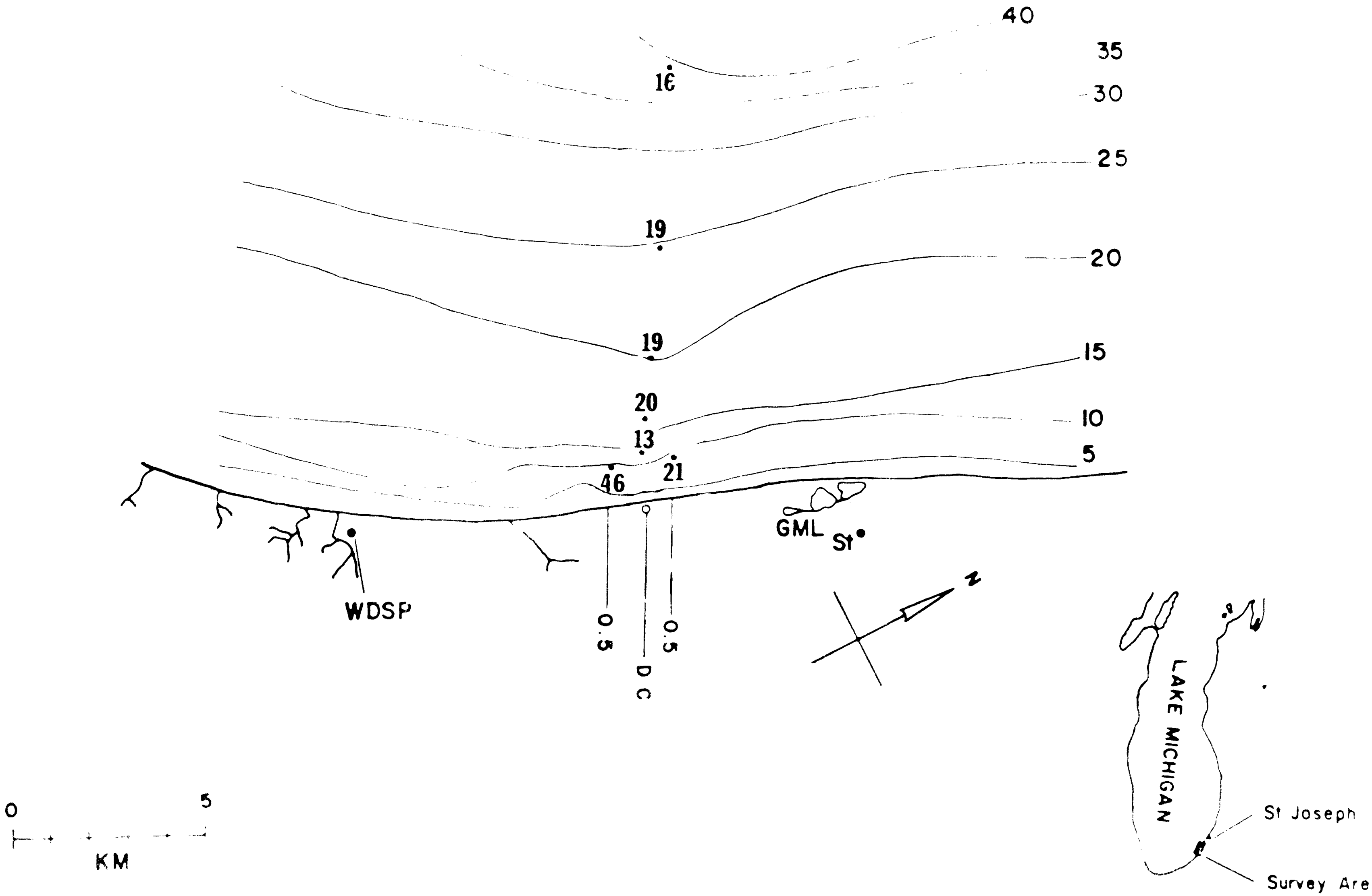

Figure 29. The spatial distribution of relative [illegible] abundance (% of total zooplankton assemblage) at 7 stations sampled on [illegible] September 19[illegible].

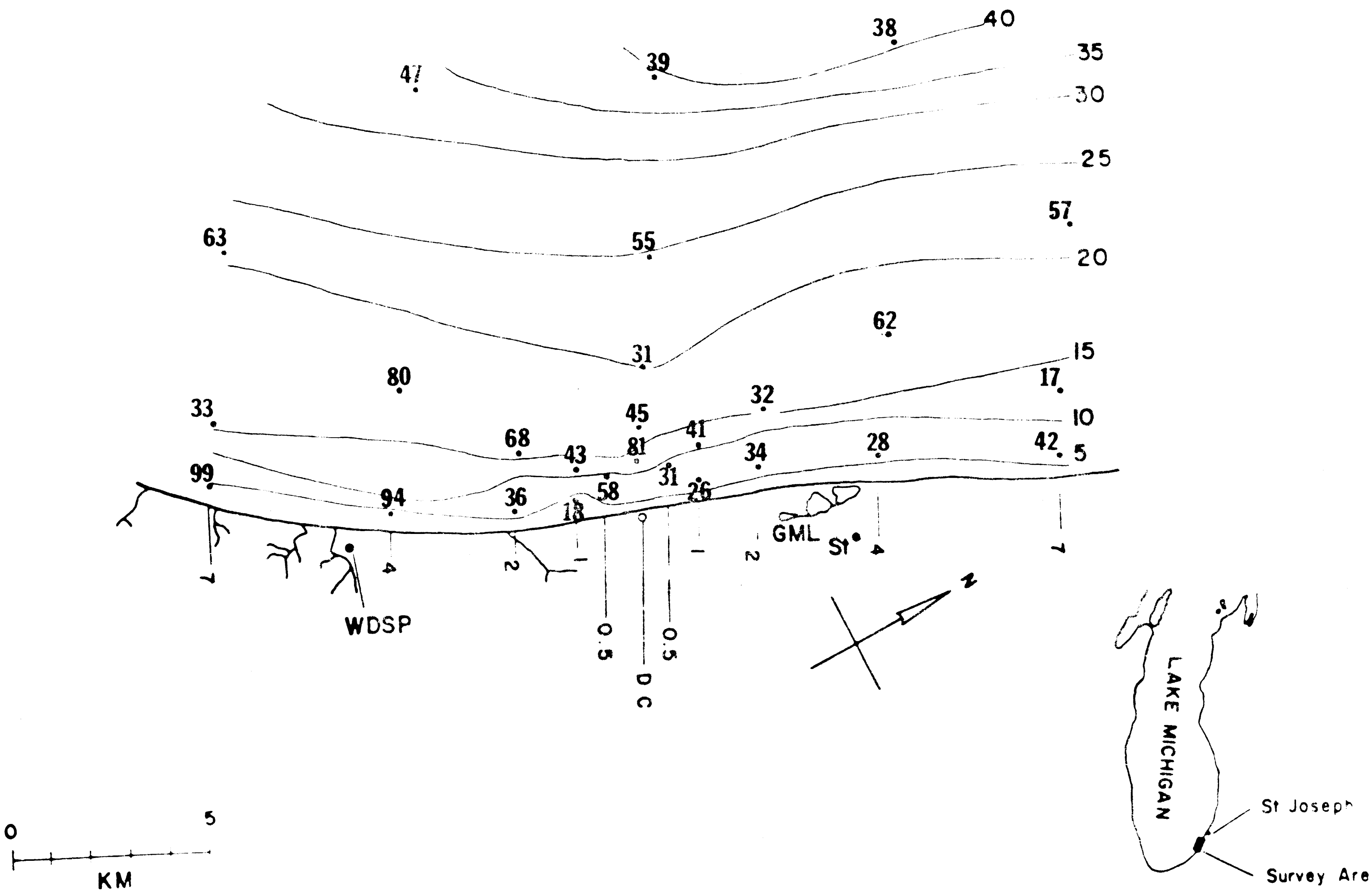

Figure 30. The spatial distribution of total zooplankton counts (individuals per liter) at 28 stations on 15 October 1972.

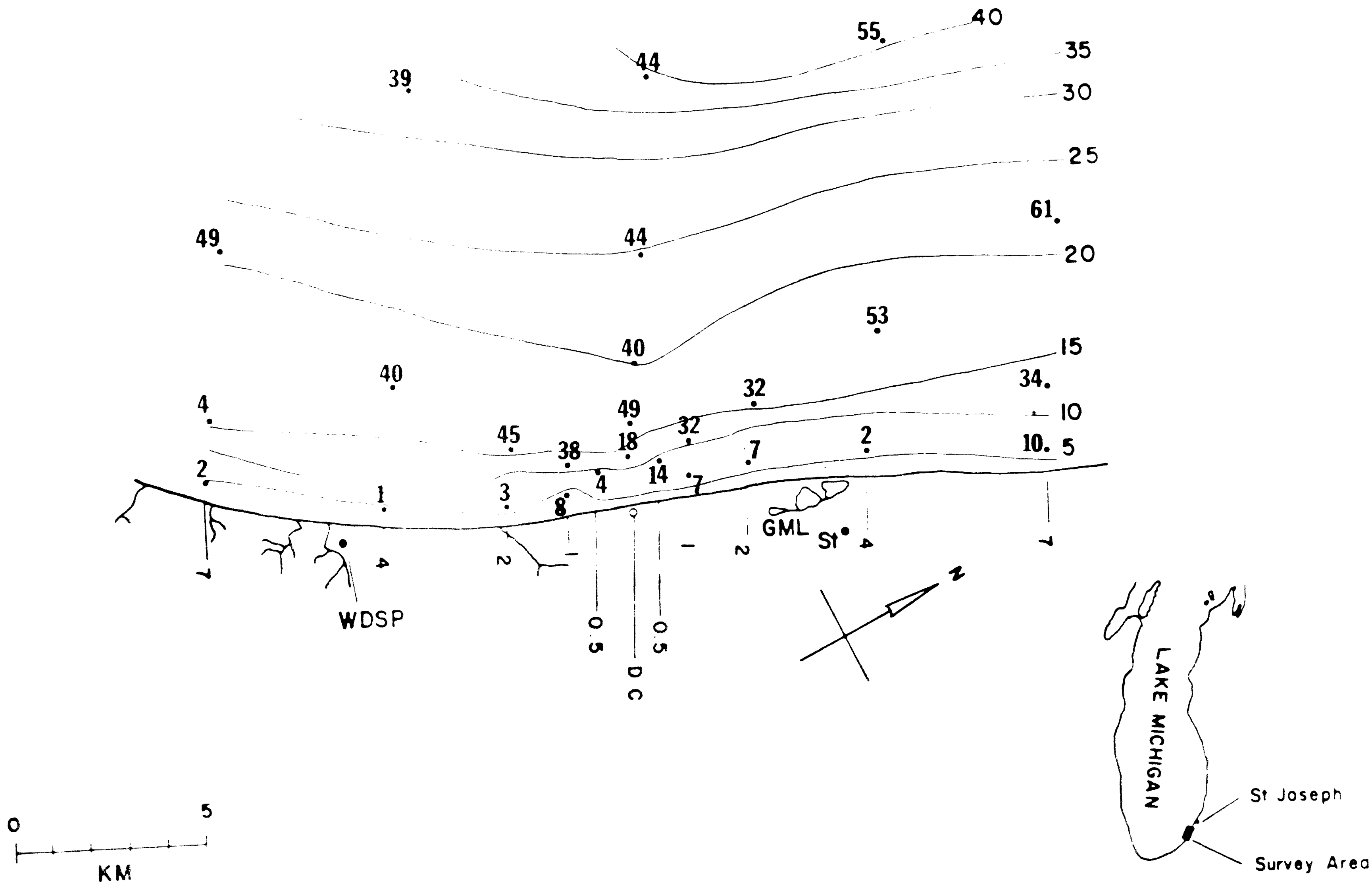

Figure 31. The spatial distribution of relative immature calanoid copepodids abundance (% of total zooplankton assemblage) at 28 stations sampled on 15 October 1972.

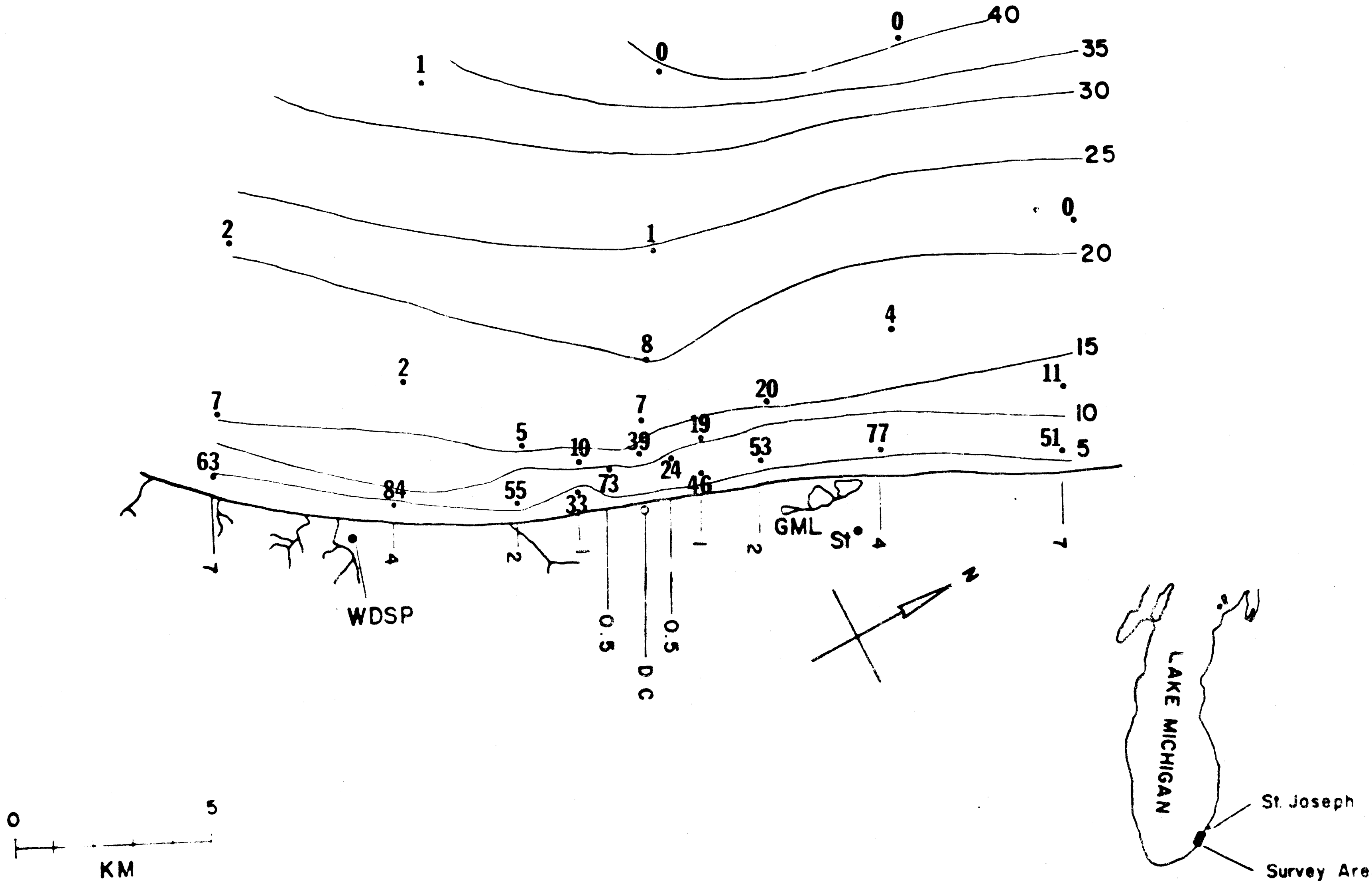

Figure 32. The spatial distribution of relative *Bosmina* abundance (% of total zooplankton assemblage) at 28 stations sampled on 15 October 1972.

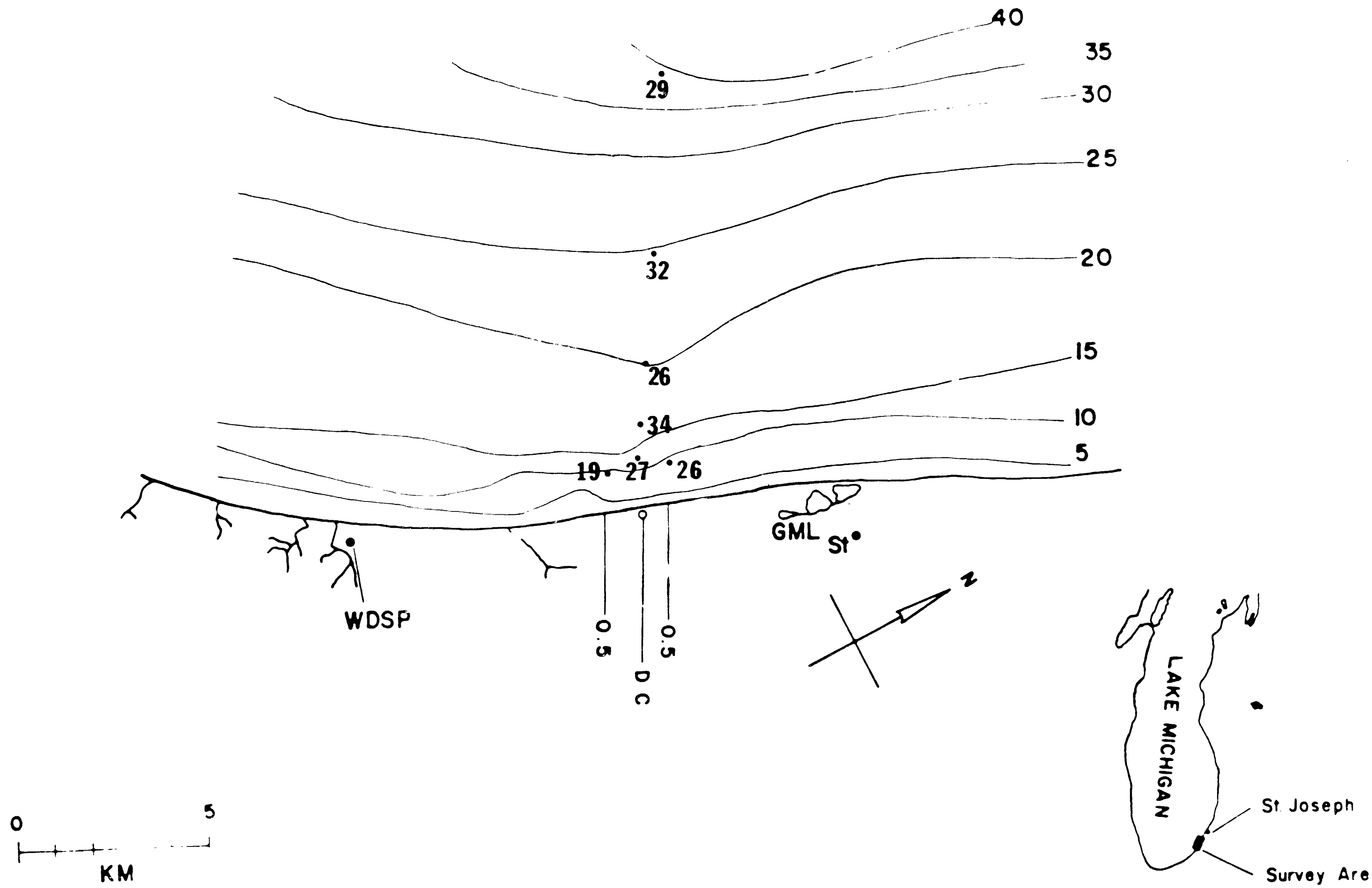

Figure 33. The spatial distribution of total zooplankton counts (individuals per liter) at 7 stations on 3 November 1972.

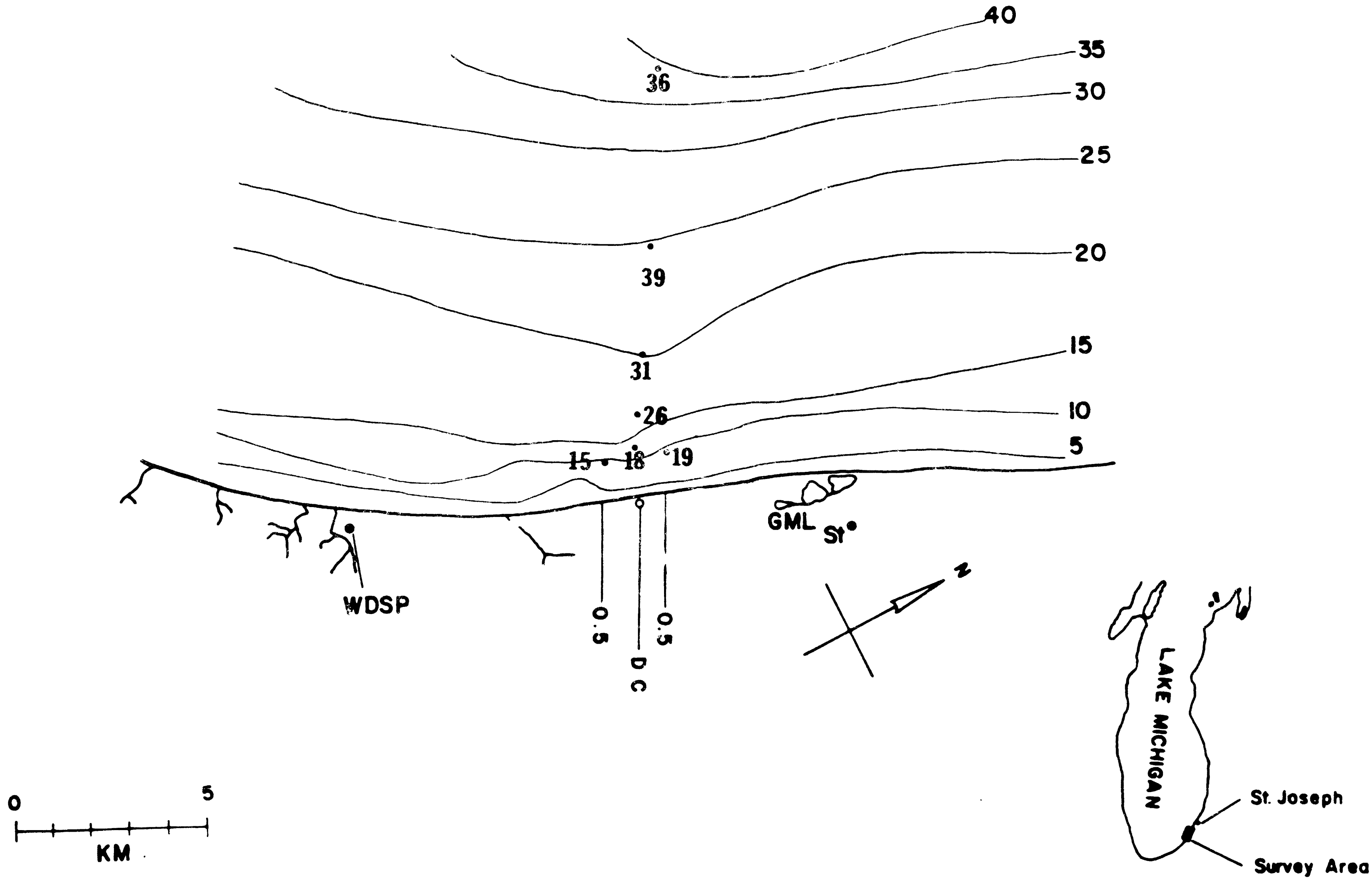

Figure 34. The spatial distribution of relative immature calanoid copepodids abundance (% of total zooplankton assemblage) at 7 stations sampled on 3 November 1972.

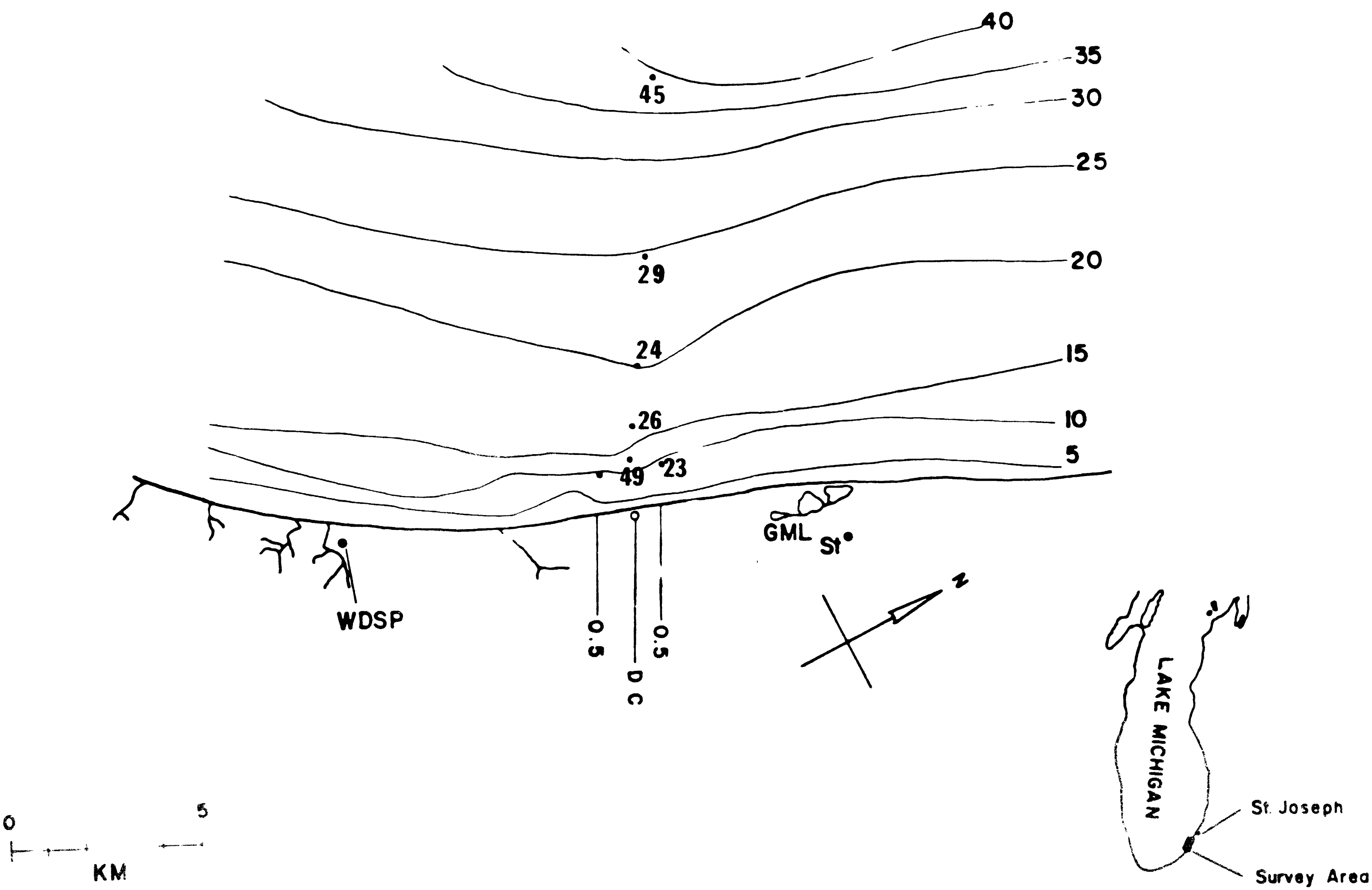

Figure 35. The spatial distribution of relative immature cyclopoid copepodids abundance (% of total zooplankton assemblage) at 6 stations sampled on 3 November 1972.

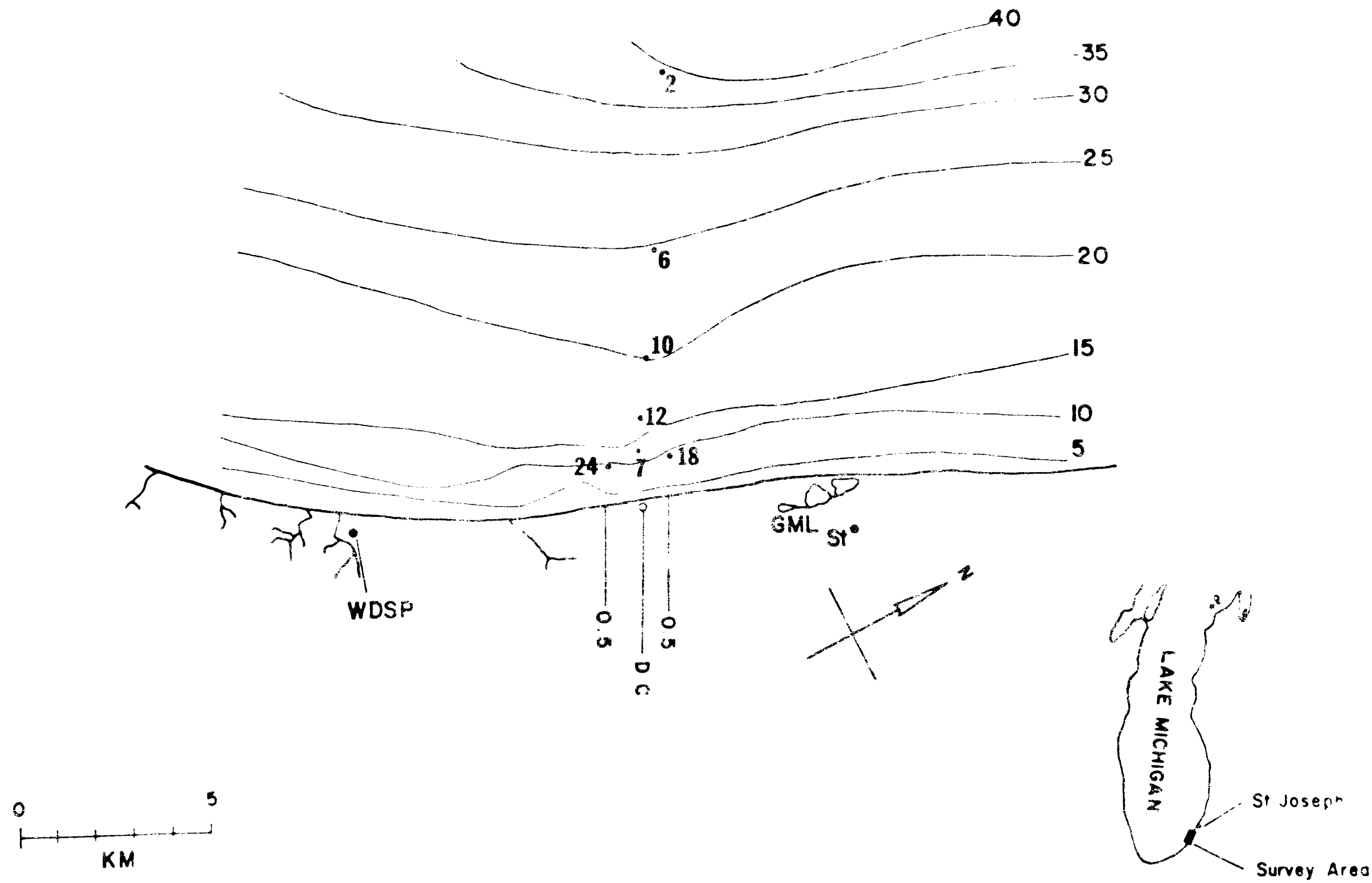

Figure 36. The spatial distribution of relative *Eubosmina* abundance (% of total zooplankton assemblage) at 7 stations sampled on 3 November 1972.

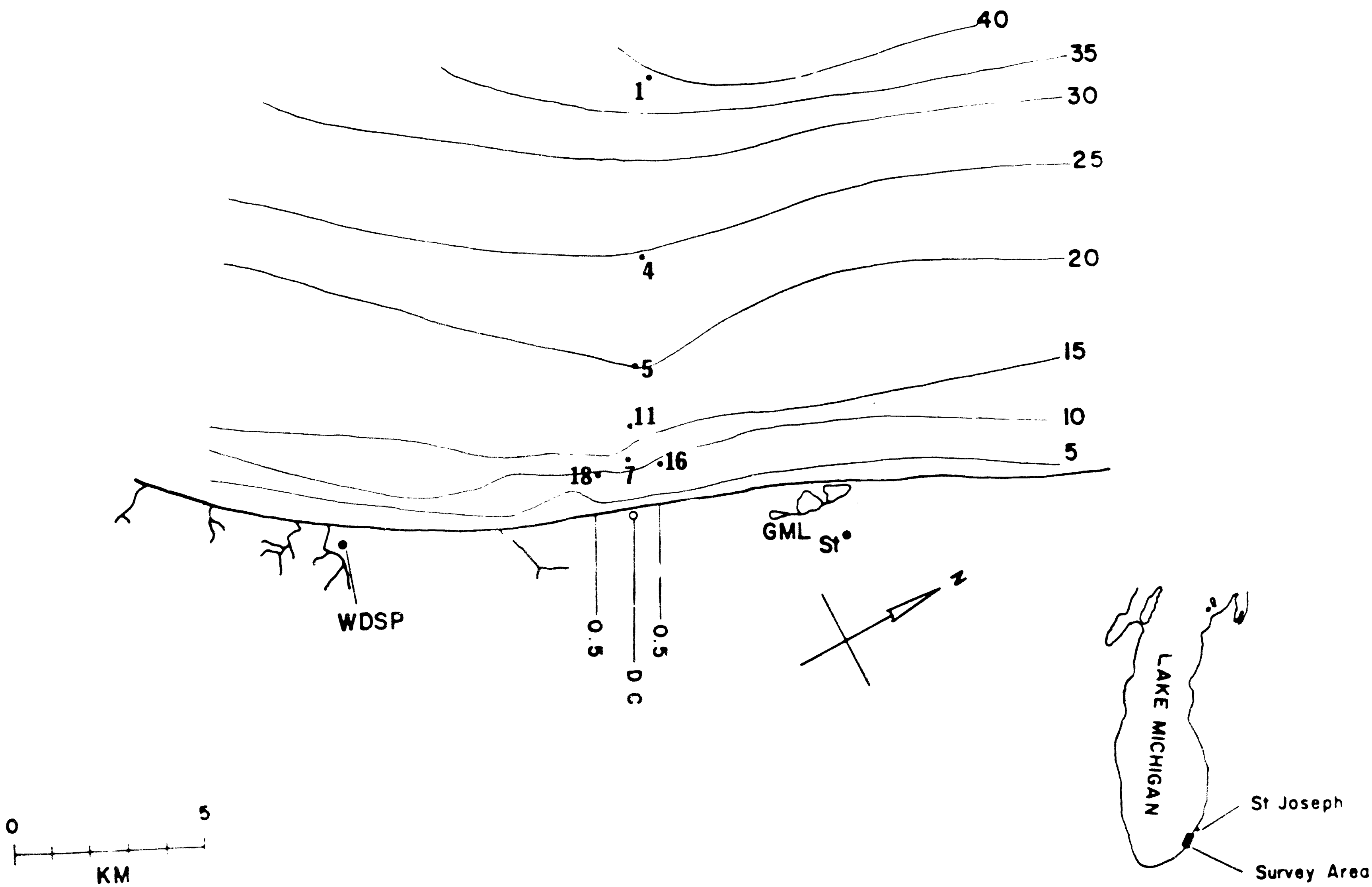

Figure 37. The spatial distribution of relative *Daphnia* abundance (% of total zooplankton assemblage) at 7 stations on 3 November 1972.

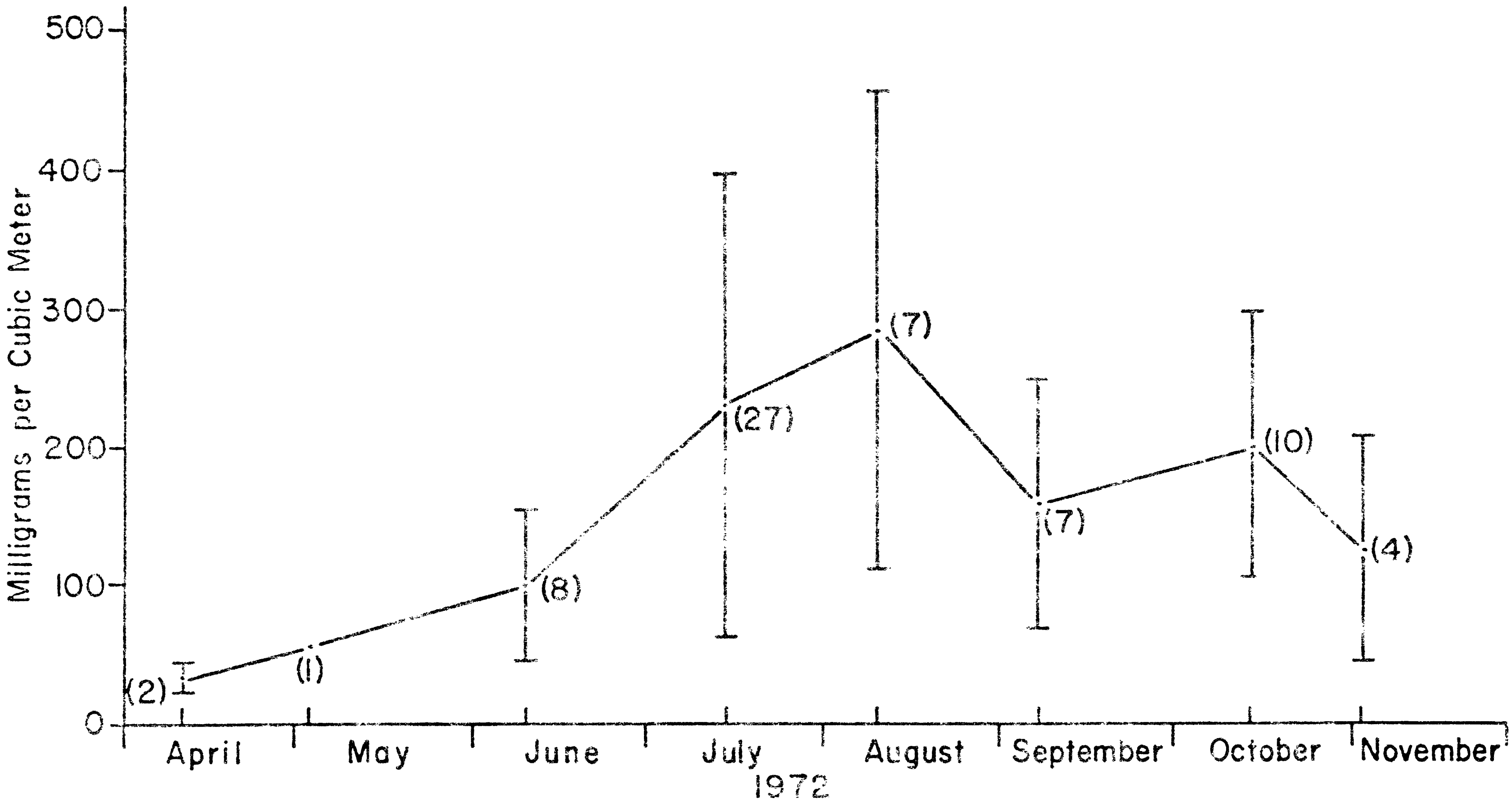

Figure 38. Zooplankton dry weight per unit volume (milligrams per m^3) for all stations where data are available, on 8 dates in 1972. Error bars show $\pm$ one standard deviation between stations means on each date. The number of stations included on each date is shown in parentheses.

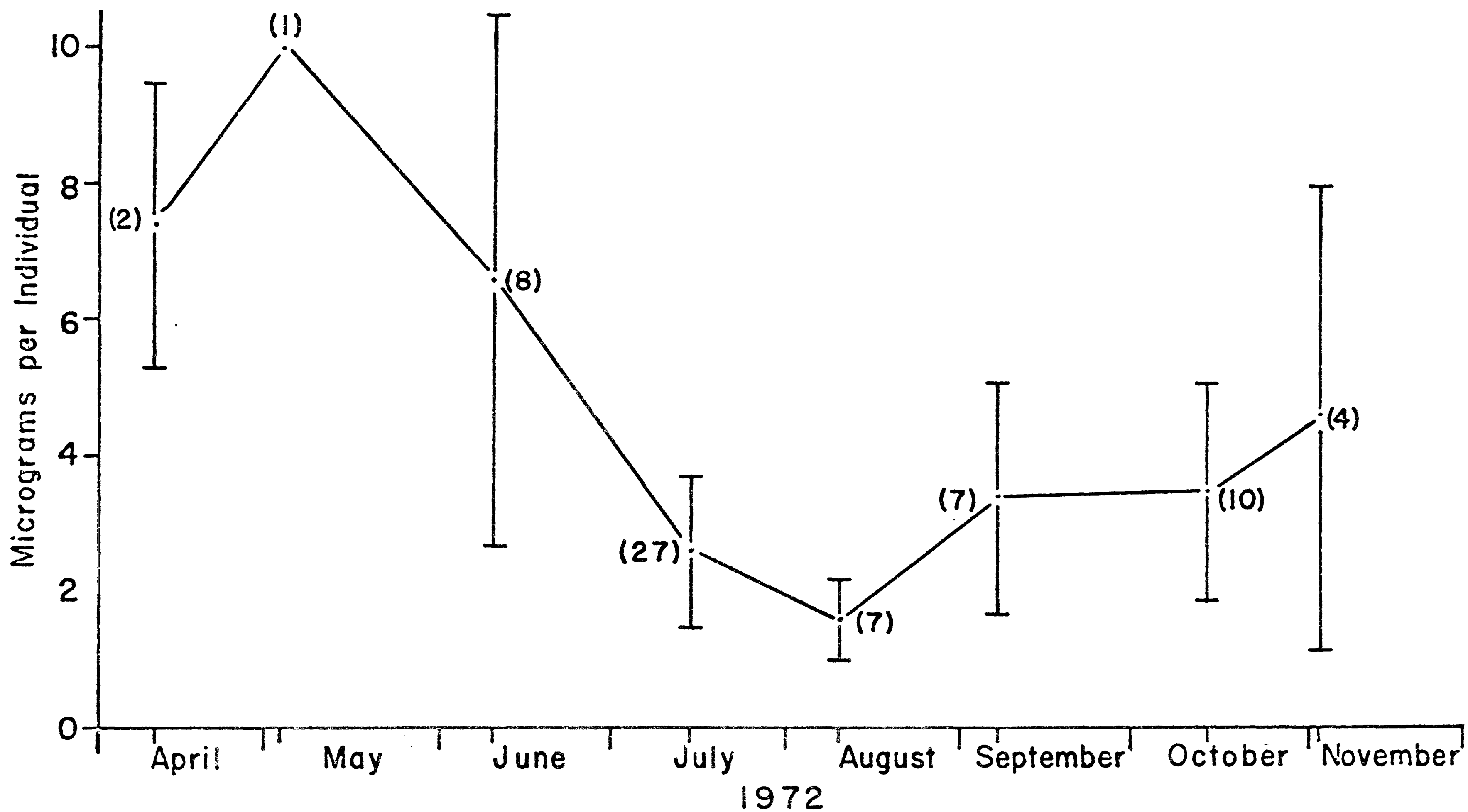

Figure 39. Zooplankton dry weight (micrograms per individual) for all stations where data are available, on 8 dates in 1972. Error bars show ± one standard deviation between station means on each date. The number of stations included on each date is shown in parentheses.

repeated here. Figures 38 and 39 are intended to replace the incomplete versions of them which were released in the interim zooplankton report issued in January 1973.

Some Speculations Based on the 1972 Zooplankton Data

The following broad conclusions emerge from the foregoing discussion:

1. In spring, total abundances were low, dominated by copepods, and inshore-offshore differences were unimportant.

2. As the water warmed, an inshore assemblage developed which typically was bounded by the 15-meter depth contour; it is characterized by a scarcity of copepods, and the dominance of small cladocerans (*Bosmina*).

3. In fall the inshore fauna persists, but is dominated by medium-sized to large cladocerans of several genera (*Daphnia, Holopedium, Eubosmina*), and immature copepods.

Consider also the following points:

1. The direct deleterious effects of the heated effluent may be expected to be greatest in summer, when ambient temperatures are highest, because the sum of ambient temperature and plant will approach or exceed the thermal death point (ca. 35 - 40C) of the animals.

2. *Daphnia galeata mendotae* under favorable conditions is capable of a population growth rate of 25% per day -- a population turnover time of only 4 days (Hall, 1964). Smaller parthenogenetic cladoceran species like *Bosmina longirostris* probably can reproduce even faster. Copepods have much lower reproductive rates; their population turnover times are on the order of a few weeks or more.

3. An animal with a high reproductive rate can sustain a high mortality rate without facing extinction.

When these points are considered, it is possible that, to the extent that the 1972 data are typical, the most drastic effects of the cooling water on the zooplankton will be applied at the time and place where the zooplankton populations there are best able to withstand such effects.

Comparison of Past and Present Methods of Zooplankton Enumeration

In order to test whether our present methods of zooplankton enumeration give comparable results to those collected in earlier surveys, we re-counted a few samples which were collected in 1970 and 1971. The early samples were identified only to higher categories. We counted the same samples to species, and then summed them to the same higher categories. Table 36 shows such data for 3 dates in 1970 and one in 1971. All refer to station DC-6. There is close agreement between the two methods. The absence of nauplii and *Tropocyclops* in both counts can be attributed to the coarser mesh net used in 1970.

Comparison of 1972 Zooplankton Counts With Earlier Data

As stated earlier, the 1971 data have not yet been reported, but they are being worked up as time permits, and will be included in subsequent reports. Counts of samples collected at station DC-6 on 4 dates in 1971 (as well as 3 dates in 1970) are compared with the 1972 DC-6 counts from the same dates in Table 37. The April 1971 fauna was very similar to that found in April 1972. The July samples differ considerably. In July 1971 there were less than half as many animals as in July 1972. The qualitative composition of the fauna was similar, but numbers of nauplii and *Bosmina* were much smaller in 1971. The July 1970 sample had an even smaller total; again, *Bosmina* counts were far smaller than in 1972. Nauplii were not sampled in 1970, which also diminishes the total.

Table 36. Comparison of zooplankton counts subsampled with a pipette (A) and the same samples subsampled with a Folsom plankton splitter (B) from station DC-6 on four dates in 1970 and 1971.

	10 July 1970*		28 Sept 1970*		12 Nov 1970*		15 April 1971**	
	A	B	A	B	A	B	A	B
Nauplii	***		***		***		***	600
Cyclopoid copepodids	13,500	12,400	1,700	1,400	2,200	2,100	3,200	2,900
Diaptomid copepodids	5,000	4,800	12,000	10,400	8,800	8,100	1,600	2,100
Epischura			100	90	50	40		
Eurytemora		40		10	20	70		
Limnocalanus	20	10	500	300	20	40		
Bosminidae	4,600	4,420	1,900	1,600	2,000	1,700		
Ceriodaphnia	20	10	10					
Chydorus				10				
Daphnia	100	80	5,000	4,000	600	700		
Diaphanosoma			200	100	10	30		
Holopedium			10	40	30	40		
Leptodora			80	40		10		
Polyphemus	400	200						
Asplanchna	50	60	400	300	10	60		
TOTAL	23,000	22,100	21,900	18,200	13,800	12,700	4,800	5,600

*Collected with #5 mesh net.

**Collected with #10 mesh net.

***Nauplii were not enumerated by the earlier methods.

Table 37. Comparison of samples collected at station DC-6 during four months in 1970, 1971, and 1972. All enumerated recently by present methods.

	APRIL		JULY			SEPTEMBER			NOVEMBER		
SPECIES	15** 1971	12** 1972	10* 1970	9** 1971	16** 1972	28* 1970	2** 1971	8** 1972	12* 1970	8** 1971	3** 1972
Copepod nauplii	600	500		4,900	35,700		2,100	2,400		700	1,200
Cyclopoid copepods											
Immature copepodids	1,400	300	4,000	11,500	11,800	500	26,100	9,300	1,400	7,900	13,300
Cyclops bicuspidatus thomasi	1,500	1,300	8,500	2,500	12,800	900	9,300	2,000	700	400	700
Cyclops vernalis							20	20			
Tropocyclops prasinus mexicanus	30	10		70	20		2,200	500		1,200	400
Calanoid copepods											
Immature copepodids	200	300	2,100	9,000	10,300	9,200	12,400	18,400	4,600	7,400	10,600
Diaptomus ashlandi	1,200	1,900	1,900	900	4,000	900	2,300	1,400	800	300	500
Diaptomus minutus	400	100	500	1,000	500	100	300	300	1,300	200	300
Diaptomus oregonensis	200	60	300	500	100	30	500	300	1,300	700	1,000
Diaptomus sicilis	50	100	20	20	50	200		20	30	200	200
Epischura lacustris						90	50	50	40	40	60
Eurytemora affinis			40		60	10	100		70		
Limnocalanus macrurus		60	10	20	200	300		30	40	40	40
Harpacticoid copepods											
Canthocamptus sp.					20						
Cladocerans											
Bosmina longirostris		40	4,400	21,100	51,500	500	18,300	200	400	100	100
Ceriodaphnia quadrangula			10		30		70				
Chydorus sphaericus						10				30	

Table 37, cont'd.

SPECIES	APRIL 15 1971**	APRIL 12 1972**	JULY 10 1970*	JULY 9 1971**	JULY 16 1972**	SEPTEMBER 28 1970*	SEPTEMBER 2 1971**	SEPTEMBER 8 1972**	NOVEMBER 12 1970*	NOVEMBER 8 1971**	NOVEMBER 3 1972**
Daphnia galeata mendotae				70	100	400	300	2,400	300	3,200	200
Daphnia longiremus								40			
Daphnia retrocurva			80	300	700	3,600	14,400	4,500	400	500	200
Diaphanosoma leuchtenbergianum						100	20	30	30	10	90
Eubosmina coregoni			20			1,100	100	400	1,300	4,800	500
Holopedium gibberum				20		40	600	1,200	40	700	40
Leptodora kindtii						40		100	10	10	
Polyphemus pediculus			200	400	60		20	10			
Rotifers											
Asplanchna sp.			60	100	1,000	300	700	80	60	40	
TOTAL	5,600	4,700	22,100	52,500	128,900	18,200	89,800	43,600	12,700	28,600	29,400

*Collected with #5 mesh net.

**Collected with #10 mesh net.

The September 1971 counts are higher than those from 1972, chiefly due to higher cyclopoid copepod, *Bosmina*, and *Daphnia retrocurva* counts in 1971. Recall that by September 1972 the offshore *Bosmina* population had crashed. The September 1970 total is much smaller than that in 1972, mainly because cyclopoid copepods were rarer in 1970, and nauplii were unsampled then. *Daphnia galeata mendotae* and *Holopedium gibberum* were also rarer in 1970 than in 1972. Again, in all three years the species list is quite similar.

The November 1971 and November 1972 totals for station DC-6 were similar, but in 1972 there were more copepods and fewer cladocerans (*Daphnia galeata mendotae, Eubosmina coregoni*, and *Holopedium gibberum*). The November 1970 collection resembled that from 1972 except that fewer immature copepodids were found in 1970, and nauplii were unsampled then. The November species list is comparable for all three years.

More rigorous comparison between years must be based on more stations, because as the 1972 data show, there can be great variability between sampling stations on a given date.

Work Plan for Zooplankton Pump Entrainment Study

<u>The problem</u>: To determine the numbers and kinds of zooplankton which are entrained by the cooling water pumps, and the effects of passage through the system on them.

<u>Requirements</u>:

1. Devise a sampling system which collects adequate water volume (ca. 0.25 m^3/min) with minimum damage to the plankton.

2. Devise a plan to obtain representative samples from the incoming water so that the same water mass can be sampled at the discharge. This must be done so that the system is sampled adequately, but with minimum sampling effort.

3. Devise a similar sampling plan for the discharge area.

4. Devise a simple, effective means of determining whether a zooplankter is alive or dead.

5. Devise an incubation system to be used for discharge samples, which mimics the thermal decay that the plume water experiences.

6. Devise a statistical design with adequate replication to provide conclusive results.

7. Meet requirements 1 - 6 in time so that mechanical effects of cold water pumping this summer can be conclusively determined.

8. Meet requirements 1 - 7 in time so that as soon as warmed water is pumped its effects on the zooplankton can be conclusively determined.

Progress to date: We began work on this problem in January 1973. We have obtained two diaphragm pumps which we believe meet requirement #1. Preliminary sampling conducted in January and February indicated that zooplankters are vertically homogeneous in the intake forebay, but that they are horizontally nonuniform. Further studies planned for March and April should meet requirements #2 and #3. Progress toward accomplishment of requirement #4 has been disappointing so far. We have to date not been able to verify that the vital staining method of Dressel *et al.* (1972) works on our material. Other methods are being evaluated in the laboratory.

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Psammo-Littoral

The psammo-littoral portion of the study is not completed at this time and is omitted from the report. Plans are to issue that data under separate cover later in the spring of 1973.

A.6 *Study of Aquatic Macrophytes*

An underwater study was conducted off the Donald C. Cook Nuclear Plant for macrophyton (rooted aquatic plants) on 28 October 1972. Diving operations were conducted from an 18 foot pontoon boat owned by the Indiana and Michigan Electric Company. The support vessel was powered by a 20 horsepower outboard engine and towed the diver along four transects (Fig 40) at approximately 2 knots. The towing apparatus consisted of 100 feet of 3/8 inch nylon line tied at one end to a bridle on the support vessel. A tow bar was attached to the other end of the tow line.

Surface supplied diving equipment was used for this survey. Air was supplied by a high pressure cascade system and a hard wire communication system was used to relay the diver's observations to surface personnel. The diver wore a variable volume dry suit which allowed control of displacement and buoyancy.

This survey began north of the Cook Plant. Transect 1 was started at a depth of 20 feet and continued in line with the North Range Poles out to a depth of 50 feet. The diver stayed underwater and the support vessel proceeded approximately 1300 feet south. Transect 2 started at a depth of 50 feet and continued in toward shore to a depth of 15 feet. The diver surfaced and the support vessel proceeded to the area south of the Cook Plant. Transect 3 started at a depth of 18 feet and continued offshore directly in line with the South Range Poles out to a depth of 50 feet. The diver again stayed underwater as the support vessel proceeded approximately 1300 feet north. Transect 4 started at a depth of 50 feet and proceeded back toward shore to a depth of 15 feet. The transects are shown in Figure 40.

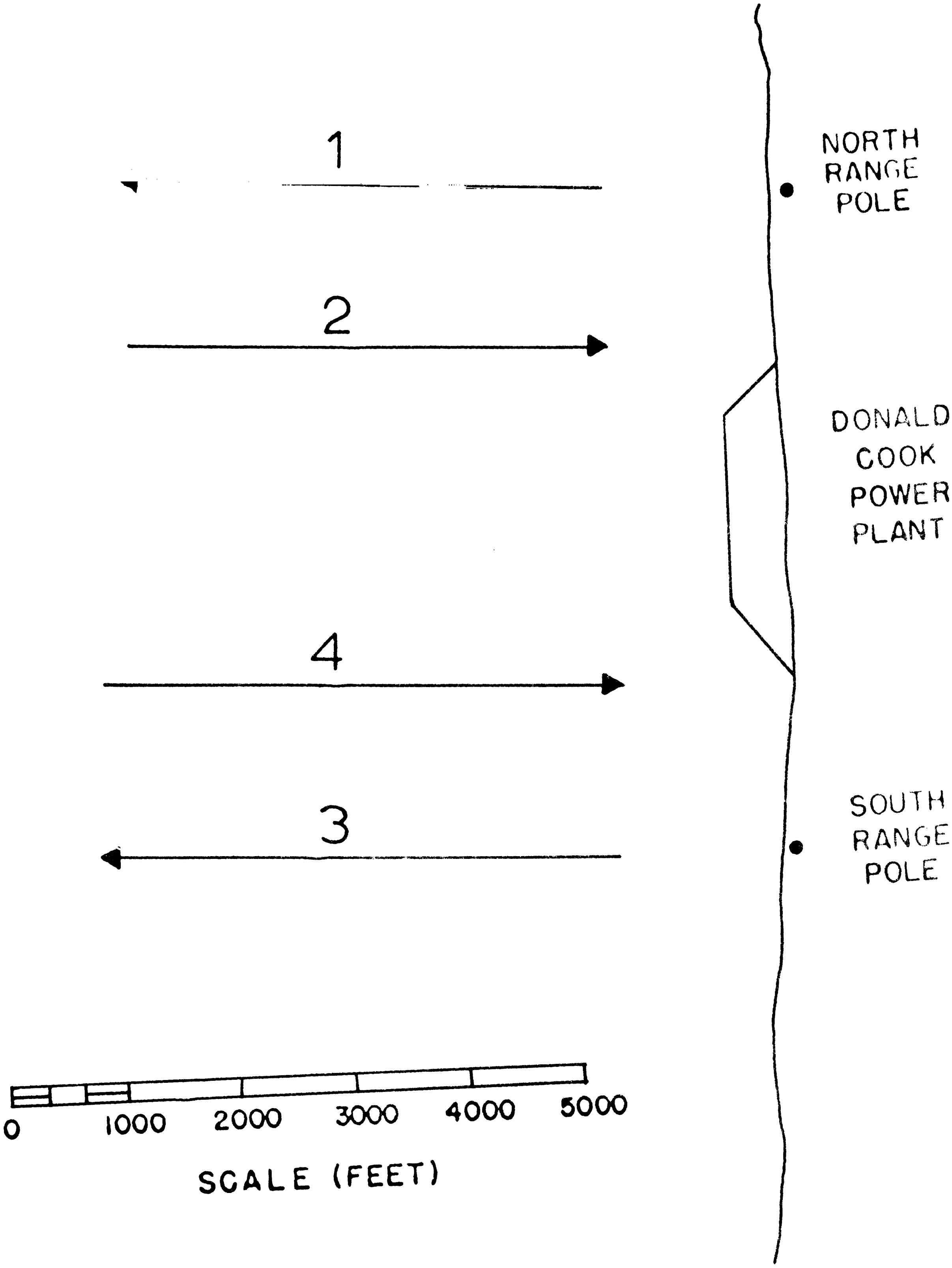


Figure 40. Macrophyte Survey, 28 October 1972.

Date	28 October 1972 Dive No. 1
Location	Transect No. 1 - directly off the North Range Poles
Depth	20-50 ft
Team	Diver/Supervisor - Robert F. Anderson Tender - Tom Bottrell Boat Operator - Bill Yocum
Dive Time	40 minutes

Depth (ft)	Observations
20	Near zero visibility. Water temperature 52°F. Bottom fine clean sand exhibiting bifurcating ripple marks with wave lengths of 6 inches and heights of 1.5-2 inches.
15	Clean fine sand bottom. Bifurcating ripple marks similar to those observed at 20 ft. Very little detritus in the troughs of the ripple marks.
14	Bifurcating ripple marks with wave lengths of 6 inches. Clean sand bottom with very little detritus in between ripple marks.
20	Clean fine sand bottom.
23	Fine sand bottom exhibiting bifurcating ripple marks with wave lengths varying from 3-6 inches. Clean sand bottom indicates a high degree of turbulence. Observed a patch of wooden debris.
26	Large bifurcating ripple marks with wave lengths varying from 18-24 inches and heights varying from 4-6 inches. Bottom type composed of a medium sand. Very little detritus accumulated in the troughs of these large ripple marks.
25	Large bifurcating ripple marks similar to those found at 26 ft, but these have smaller ripple marks in between the large ones. Little detritus in the troughs of ripple marks.
23	Medium sand bottom exhibiting ripple marks with wave lengths varying from 6-8 inches and heights varying from 2-3 inches.
21	Small bifurcating ripple marks with wave lengths varying from 4-6 inches and 1.5 inches in height. Bottom visibility about 1 ft.
25	Bottom type fine sand with bifurcating ripple marks. Observed occasional piece of wood debris and detritus.

Depth (ft)	Observations
27	Clean fine sand bottom exhibiting ripple marks identical to those observed at 21 ft.
30	Fine sand bottom exhibiting bifurcating ripple marks with wave lengths varying from 2-4 inches and 1 inch in height. Bottom water temperature was 52°F.
32	Observed small silt pocket about 1 ft in diameter.
34	Observed another small pocket of silt.
35	Passed another small area of silt. Fine sand bottom with bifurcating ripple marks. Very little detritus in troughs.
37	Bottom visibility 1 ft. Bifurcating ripple marks with wave lengths varying from 4-6 inches and 1 inch in height.
38	Little detritus in troughs of ripple marks.
40	Passed silt pocket 18 inches in diameter. Ripple marks identical to those observed at 37 ft.
43	Bifurcating ripple marks exhibiting wave lengths of 1 ft and heights of 2 inches. Passed one silt pocket about 3 ft in diameter and another estimated to be 14-18 ft wide. Areas of silt contain dark grey gelatinous silt 4-5.5 inches in depth.
44	Bifurcating ripple marks with wave lengths varying from 4-6 inches and a height of 1.5 inches observed. Fine layer of detritus overlaying fine sand.
45	Passed another silt pocket about 4 ft wide. Surface of silt pocket covered with small dark spots 1/4 inch in diameter.
46	Passed another silt pocket about 6-8 ft wide and 2-3 inches in depth. Small dark spots also present on the surface of the silt. Bifurcating ripple marks identical to those observed at 44 ft. Larger accumulations of detritus in the troughs between ripple marks.
47	Passed large pocket of silt estimated 25-30 ft wide and 2-3 inches deep. Small dark spots 1/4 inch in diameter covering the surface of silt pockets.
50	Fine sand bottom exhibiting bifurcating ripple marks with wave lengths varying from 4-6 inches and a height of 1/5 inch. Passed area of silt about 10-12 ft wide. Surface of silt covered with black spots.

The trend of the ripple marks observed during Transect 1 was in a north-south direction. No aquatic macrophytes were observed along this transect. The frequent storms that have occurred this fall have kept detritus from accumulating on the bottom especially in the area of the sandbars in shallow water. The bottom along this entire transect had been swept clean of detritus indicating a high degree of turbulence. The diver stayed underwater and was towed south to the starting point of Transect 2.

Date	28 October 1972 Dive No. 1
Location	Transect No. 2 - 1300 ft south of Transect No. 1
Depth	50-15 ft
Team	Diver/Supervisor - Robert F. Anderson Tender - Tom Bottrell Boat Operator - Bill Yocum
Dive Time	41 minutes

Depth (ft)	Observations
50	Passed several silt pockets varying around 8-12 ft in width. Observed several more silt pockets about 15-20 ft in width and 2-3 inches in depth. Small dark spots 1/4 inch in diameter covering surface of silt pockets. Passed another silt pocket about 20-25 ft wide and 2-3 inches in depth. Silt pockets composed of dark grey gelatinous silt with small dark spots covering the surface.
48	Fine sand bottom exhibiting bifurcating ripple marks with wave lengths of 4-6 inches and heights of 1-2 inches. Passed several silt pockets about 15-20 ft in diameter.
47	Passed several silt pockets about 3 ft in diameter. Observed silt pocket about 20 ft wide and 4-6 inches in depth. Fine sand bottom exhibiting ripple marks identical to those observed at 48 ft. Thin layer of detritus in the troughs between ripple marks. Passed an occasional patch of wood debris.
45	Large ripple marks with a wave length of about 3 ft and height of 6 inches.

Depth (ft)	Observations
40	Fine sand bottom exhibiting bifurcating ripple marks with wave lengths varying from 4-6 inches and a height of 1 inch. Passed by a large pocket of silt estimated 30 ft wide and 6 inches deep.
36	Observed a few small pockets of silt 1-2 ft in diameter.
34	Passed a silt pocket about 6 ft wide and 2 inches deep. Observed several silt pockets 1-2 ft in diameter.
32	Fine sand bottom exhibiting bifurcating ripple marks with wave lengths of 4-6 inches.
30	Passed a large area of silt about 40 ft wide and 2-3 inches deep. Passed another area of silt estimated to be 30 ft wide. Fine sand bottom.
29	Fine sand bottom exhibiting bifurcating ripple marks with wave lengths of 4 inches. Passed several pockets of silt with widths estimated from 20-40 ft and depths of 2-3 inches.
25	Fine sand bottom. Bifurcating ripple marks with wave lengths of 4-6 inches and a height of 1.5 inches.
20	Fine sand bottom exhibiting bifurcating ripple marks identical to those observed at 25 ft.
24	Clean sand bottom. No detritus or debris found in this area near a sandbar.
24	Parallel ripple marks with a wave length of 8 inches and a height of 2 inches.
24	Fine sand bottom exhibiting bifurcating ripple marks. Observed several chunks of grey clay on the bottom.
21	Fine sand bottom exhibiting bifurcating ripple marks with wave lengths varying from 4-6 inches and a height of 2 inches.
16	Bifurcating ripple marks same as those observed at 21 ft. Little detritus present.
14	Conditions same as those observed at 16 ft.
20	Observed a small pocket of silt about 6 ft wide. Bifurcating ripple marks present with wave lengths varying from 4-6 inches and a height of 2 inches.
15	Dive terminated. Bottom water temperature was 52°F.

Small amounts of detritus and debris were evident along this transect when compared to the conditions observed last year. No macrophytes were observed on Transect 2.

Date	28 October 1972	Dive No. 2
Location	Transect No. 3	- directly off the South Range Poles
Depth	18-50 ft	
Team	Diver/Supervisor Tender Boat Operator	- Robert F. Anderson - Tom Bottrell - Bill Yocum
Dive Time	31 minutes	

Depth (ft)	Observations
18	Bottom type composed of medium sand exhibiting bifurcating ripple marks with a wave length of 6 inches and a height of 2 inches.
21	Ripple marks with a wave length of 6 inches and a height of 2 inches.
25	Bifurcating ripple marks with a wave length of 4 inches and a height of 1.5 inches.
27	Clean fine sand bottom with ripple marks same as those found at 25 ft.
28	Passed several pockets of silt about 6 ft wide and 2 inches deep.
30	Observed a silt pocket 6 or 7 ft wide and 2 inches in depth. Passed a silt pocket about 12 ft wide and 3 inches deep. Passed another silt pocket about 4 ft wide and 2 inches deep. Bottom type composed of a fine sand exhibiting bifurcating ripple marks with a wave length of 2.5 inches and a height of 3/4 inch. Passed another silt pocket estimated at 12 ft wide.
32	Little detritus found in between ripple marks.
36	Clean fine sand bottom exhibiting bifurcating ripple marks with a wave length of 4 inches and a height of 1 inch.

Depth (ft)	Observations
43	Bottom type composed of a medium sand exhibiting bifurcating ripple marks with wave length varying from 1 ft to 18 inches and heights varying from 2-3 inches. Fine layer of detritus in the troughs between ripple marks.
44	Observed occasional clump of detritus composed of roots from sedges that had been washed into the area.
45	Bottom type was a medium sand. Bifurcating ripple marks observed with wave lengths varying from 18 inches to 2 ft and a height of 4 inches.
45	Bottom exhibiting bifurcating ripple marks with wave lengths varying from 4-6 inches and a height of 1 inch.
46	Observed 2 small silt pockets. One was 1 ft in diameter and the other was 3 ft in diameter.
50	Fine sand bottom exhibiting bifurcating ripple marks with wave lengths from 18 inches to 2 ft and a height of 3 inches. A heavy accumulation of light brown organic material was observed in the troughs between these ripple marks. Observed a pocket of silt in the trough between the ripple marks. Observed a pocket of silt about 40 ft wide and 3 inches deep. Bifurcating ripple marks were observed on the surfaces of the silt pockets.

The trend of the ripple marks on this transect was also in a north-south direction. The surfaces of the silt pockets contained the small dark spots observed on Transect 1 and 2. The frequency and pattern of the ripple marks indicated a high degree of turbulence on the bottom. No macrophytes were observed along this transect. Diver remained underwater and was towed to the starting point of Transect 4.

Date	28 October 1972	Dive No. 2
Location	Transect 4	- 1300 feet north of Transect 3
Depth	50-15 ft	
Team	Diver/Supervisor Tender Boat Operator	- Robert F. Anderson - Tom Bottrell - Bill Yocum
Dive Time	30 minutes	

Depth (ft)	Observations
50	Fine sand bottom exhibiting bifurcating ripple marks with wave lengths of 18 inches to 2 ft and a height of 3 inches. Patches of light brown organic detritus observed in the troughs between ripple marks.
46	Fine sand bottom exhibiting ripple marks with wave lengths varying from 4-6 inches and a height of 1.5 inches.
44	Bottom type composed of a medium sand. Observed bifurcating ripple marks with wave lengths varying from 18 inches to 2 ft and a height of 3 inches. Fine layer of light brown organic detritus in the troughs between the ripple marks. Observed a few pieces of wood debris that were covered with snails.
42	Bottom type of fine sand.
38	Observed bifurcating ripple marks with wave lengths varying from 4-6 inches and a height of 1.5 inches.
35	Fine sand bottom exhibiting bifurcating ripple marks with a wave length of 2 incnes and a height of 3/4 inch.
33	Observed two silt pockets. One was about 2 ft wide and the other was about 4 ft wide. Both were 2-3 inches in depth.
30	Passed a silt pocket that was about 10 ft wide. Observed bifurcating ripple marks with a wave length of 3 inches and a height of 3/4 inch. Passed three silt pockets that had estimated widths of 10, 15, and 3 ft.
28	Bottom composed of a fine sand exhibiting bifurcating ripple marks with a wave length of 3 inches. Observed two pockets of silt. One was about 3 ft in diameter and the other was estimated at 12 ft in diameter.
25	Observed bifurcating ripple marks with a wave length of 3 inches and a height of 3/4 inch. Found several silt pockets about 3 ft wide in this area.
22	Medium sand bottom exhibiting bifurcating ripple marks with wave lengths varying from 4-6 inches and a height of 1.5 inches.
15	Fine sand bottom exhibiting bifurcating ripple marks with wave lengths varying from 4-6 inches and a height of 1.5 inches. Dive was terminated.

The surface of the silt pockets observed along this transect contained the small dark spots observed on Transects 1, 2, and 3. No macrophytes were observed on this transect. The abundance of ripple marks along this entire transect indicated a high degree of turbulence on the bottom.

A.7 *Study of Benthic Organisms*

S. C. Mozley

Introduction

In order to make what follows as clear as possible, a review of the benthos survey program is presented. Starting in July 1970, major surveys of a 46-station grid were conducted in spring, summer, and fall, through April 1972. From these surveys, selected samples were analyzed to the most detailed taxonomic levels achievable at the time. The results of the July 1970 survey have been reported in Part IX of our report series. Using the same methods, we processed samples from November 1970, and April and July 1971, to obtain seasonal information on community structure.

In May 1972, the sampling design was changed to allow for more rigorous statistical treatment of benthos data and to allow determination of the monthly status of the benthos near the plant site between major seasonal surveys. A stratified random sampling design was instituted in the seasonal survey of July 1972 to satisfy prerequisites for statistical analysis and to reduce variances of quantitative estimates.

At present, benthos data have been processed at preliminary levels through the first stratified random survey of July 1972. The program just described was continued through October 1972 and will continue in 1973. For the monthly surveys nine stations of the original systematic survey plan were sampled in triplicate. The program now consists of major spring, summer, and fall seasonal surveys and monthly between-seasonal surveys of a nine station reduced sampling grid.

Because many discrete samples are needed for statistical analysis, the size of individual samples was reduced for the July 1972 survey by modifying

a standard ponar grab. The new ponar grab can be used to obtain samples 1/3, 2/3, or equal to an ordinary ponar, by retaining the contents of one, two, or all three compartments. The entire sample is retained from triplicate casts in the relatively depauperate beach zone, while only the central 1/3 of the grab sample is retained from each of the triplicate casts at offshore stations.

Data at the major taxon level for the seasonal surveys of September 1970 through April 1972 are given in Section 1. Statistical treatment of the data presented in Section 1 is planned for a later date. Section 2 presents the benthos community structure as determined by major taxa. A detailed analysis of the stratified random sampling seasonal survey of July 1972 is presented in Section 3.

Brief notes on topics for which limited data are available, but which are important to the considerations of effects of the plant on benthos, can be found in Sections 4 and 5. Section 4 gives information on the epibenthic, or semiplanktonic opossum shrimp, *Mysis relicta*. Preliminary qualitative information about the benthos found in the cooling water intake forebay is given in Section 5.

Section 1. <u>List of major survey data</u>

From July 1970 through April 1972, seasonal benthos data at the major taxon level were collected at 46 stations per survey. The primary objective of these surveys was to obtain a thorough background of information about seasonal and year-to-year variations in the benthos prior to plant operation. Follow-up statistical analyses of the data will be based on various recombinations of the data, depending on the patterns which appear. For instance, stations located near the plant could be averaged and compared with stations farther from the plant.

The strictly systematic selection of station locations, however, violates one of the requirements of statistical tests for differences of means, such as the t-test. Theoretically, stations within a defined region should be chosen at random, so that every point in the region has an equal chance of being sampled. Nevertheless, it is common practice in benthos surveys to ignore this requirement and assume that a strictly systematic sampling design would give the same results. The more suitable sampling design implemented in July 1972 will allow a test of the assumption that randomization of locations is not necessary.

Since we anticipate that analyses will be conducted on these earlier data, they are listed in alternating order of proximity to the plant (2 miles or less north or south from the DC transect, versus 4 or 7 miles from the DC transect), and in order of increasing distance from shore: 1/4 mile, 1/2 to 3/4 mile, 1 1/4 mile to 2 1/4 miles, 4 miles, and 7 miles (equivalent metric range: 400 m to 11 km). The techniques for these surveys have been described in Part IX of this series of reports. Tables 38 through 44 contain complete listings of available data for each major survey at the higher taxon level. Locations of the stations are shown in Figure 41.

Table 38. Numbers/m^2 of benthic macrofauna by major taxa in September, 1970. Data are based on two combined samples per station. The conversion factor for original counts is 8.67. (Amph - Amphipoda; Olig - Oligochaeta; Sphr - Sphaeriidae; Chir - Chironomidae; Hiru - Hirudinea; Gast - Gastropoda.)

Station	Amph	Olig	Sphr	Chir	Hiru	Gast	TOTAL
DC-1				-no data-			ND
NDC-.5-1	17	321		34			372
SDC-.5-1	34	1,008	399	286			1,727
NDC-1-1	26	165	8	295	8		502
SDC-1-1		69		8			77
NDC-2-1		620	34	34		8	696
SDC-2-1		113	17	8			138
NDC-4-1	8	26		26			60
NDC-7-1		78		26			104
SDC-4-1	26	69	8	234	17		354
SDC-7-1	113	182	26	104		26	451
DC-2	539	1,225	426	269	34		2,493
NDC-.25-1	373	730	113	86	34		1,336
SDC-.25-1	539	1,226	426	270	34		2,495
NDC-.5-2	60	2,260	321	191	8		2,840
SDC-.5-2	113	556	443	122		26	1,260
NDC-1-2	2,930	23,267	921	547	8	8	27,681
SDC-1-2	226	2,478	78	217	26		3,025
NDC-2-2	43	782	8	199	8		1,040
SDC-2-2	95	1,304	173	191		17	1,780
NDC-4-2	17	121		34			172
NDC-7-2				8			8
NDC-7-3	869	1,495	139	208	43		2,745
SDC-4-2	43	1,043	182	191	8	8	1,475
SDC-7-2		382	26	34			442
SDC-7-3	121	1,156	286	286			1,849
DC-3	1,112	3,964	139	295	139	26	5,675
NDC-.5-3	1,356	852	86	156			2,450
SDC-.5-3	1,339	1,286	1,286	443	104	86	4,544
NDC-2-3	452	313		620			1,385
SDC-2-3	1,678	5,590	886	782	17		8,953
DC-4	4,382	11,181	2,686	620	620	217	19,706
NDC-1-3	6,051	9,338	1,886	95		95	17,465
SDC-1-3	4,530	5,156	7,564	60		69	17,379
NDC-4-3	799	139	17	86			1,041
NDC-7-4	956	226					1,182
SDC-4-3	4,686	8,199	2,156	260		34	15,335
SDC-7-4	1,843	23,519	599	617	69	69	26,716
DC-5	5,860	4,956	460	43	17	34	11,370
NDC-2-4	3,634	4,086	617	26			6,363
SDC-2-4	4,138	7,990	495	17	17		12,657
NDC-7-5	2,234	2,625	573	26	43		5,501
SDC-7-5	1,225	4,973	478		52		6,728
SDC-4-4	3,278	3,451	104	8			6,841
DC-6	3,530	3,721	52	8			7,311
NDC-4-4	5,451	4,860					10,311

Table 39. Numbers/m^2 of benthic macrofauna by major taxa in November, 1970. Data are based on two combined samples per station. The conversion factor for original counts is 8.67. (See Table 38 for legend)

Station	Amph	Olig	Sphr	Chir	Hiru	Gast	TOTAL
DC-1				-no data-			ND
NDC-.5-1	8	34		8			50
SDC-.5-1	26	452	147	260	8		893
NDC-1-1	8	252	156				416
SDC-1-1		2,252		8	8		2,268
NDC-2-1	26	356	330	165			877
SDC-2-1		43	95				138
NDC-4-1	34			34			68
NDC-7-1		43					43
SDC-4-1		8		8			16
SDC-7-1	26			43			69
DC-2	17	2,208	808	582	8	17	3,640
NDC-.25-1	478	4,956	2,252	712	95	86	8,579
SDC-.25-1	347	4,051	313	313	17		5,041
NDC-.5-2	69	1,330	712	217	43		2,371
SDC-.5-2	69	730	860	191			1,850
NDC-1-2	52	843	234	234			1,363
SDC-1-2	95	1,043	1,017	234	8	86	2,483
NDC-2-2	47	3,025	295	286	8	8	3,669
SDC-2-2	69	1,678	478	191	34	52	2,502
NDC-4-2	78	452	52	104			686
NDC-7-2	121	1,182	43	199			1,545
NDC-7-3	504	426	34	43			1,007
SDC-4-2	34	608	1,060	252	17		1,971
SDC-7-2	26	1,017	121	104			1,268
SDC-7-3	95	39,727	5,338	2,217	26	34	47,437
DC-3	173	1,608	60	599	8	17	2,465
NDC-.5-3	1,052	3,912	1,312	382	8	95	6,761
SDC-.5-3	695	1,495	513	339			3,042
NDC-2-3	321	5,190	313	1,869	69		7,762
SDC-2-3	373	13,346	1,739	1,469	17	17	16,961
DC-4	3,373	4,347	1,704	252	60	26	9,762
NDC-1-3	2,599	1,269	269	104			4,241
SDC-1-3	2,095	10,894	3,347	504	43	443	17,326
NDC-4-3	2,382	1,017	426	208			4,033
NDC-7-4	1,582	4,712	1,034	1,034	8	17	8,387
SDC-4-3	3,173	1,286	626	139		43	5,267
SDC-7-4	712	1,878	130	208		17	2,945
DC-5	4,712	1,078	182	60			6,032
NDC-2-4	7,416	8,721	1,999	52	26	34	18,248
SDC-2-4	391	60	8	52	8		519
NDC-7-5	2,782	5,208	1,712	165	43	17	9,927
SDC-7-5	417	5,843	2,469	530	130	43	9,432
SDC-4-4	2,330	6,538	1,078	17	8	17	9,988
DC-6	4,104	3,817	264		8	8	8,201
NDC-4-4	8,799	9,068	4,660	69	8		22,604

Table 40. Numbers/m^2 of benthic macrofauna by major taxa in April, 1971. Data are based on one sample per station. The conversion factor for original counts is 18.13. (See Table 38 for legend)

Station	Amph	Olig	Sphr	Chir	Hiru	Gast	TOTAL
DC-1		90	36				126
NDC-.5-1	72	108	18				198
SDC-.5-1		72		54	18		144
NDC-1-1		126	36				162
SDC-1-1					18		18
NDC-2-1				36			36
SDC-2-1			36	18			54
NDC-4-1		18			18		36
NDC-7-1		36					36
SDC-4-1		18					18
SDC-7-1		18					18
DC-2	290	2,030	870	308		36	3,534
NDC-.25-1	181	1,939	562	290	36	36	3,044
SDC-.25-1	36	54	18	18			126
NDC-.5-2	18	271	54	235			578
SDC-.5-2		815	145	145		18	1,123
NDC-1-2	36	3,154	507	362			4,059
SDC-1-2		18				18	36
NDC-2-2	18			18			36
SDC-2-2	18	18		90			126
NDC-4-2			-no animals-				none
NDC-7-2		108	18	36			162
NDC-7-3	217	217	326	36			796
SDC-4-2	54	271	72	253	36		686
SDC-7-2		362	326	181			869
SDC-7-3	36	3,281	271	163			3,751
DC-3	18	36	652				706
NDC-.5-3	290	7,415	54	707	18		8,484
SDC-.5-3	416	598	1,160	235		36	2,445
NDC-2-3	380	3,335	471	253	18	18	4,475
SDC-2-3	453	1,468	308	108		36	2,373
DC-4	2,792	2,792	1,867	163	54	181	7,849
NDC-1-3	181	1,396	344	54	18		1,993
SDC-1-3	108	181	416	54		36	795
NDC-4-3	36	90	18				144
NDC-7-4	1,305	4,731	380	217		18	6,651
SDC-4-3	126	3,136	1,758	471	181	163	5,835
SDC-7-4	416	36	18	18	18		506
DC-5	6,943	14,340	1,142	271	54		22,750
NDC-2-4	9,391	6,327	888	18	18	18	16,660
SDC-2-4	4,858	5,148	2,918	36		36	12,996
NDC-7-5	2,737	5,874	3,118	235	145	126	12,235
SDC-7-5	416	6,907	380	145			7,848
SDC-4-4	2,465	5,692	2,284	18		18	10,477
DC-6	6,200	9,173	2,574	163			18,110
NDC-4-4	10,007	5,765	924	308			17,004

Table 41. Numbers/m^2 of benthic macrofauna by major taxa in July, 1971. Data are based on one sample per station. The conversion factor for original counts is 18.13. (See Table 38 for legend)

Station	Amph	Olig	Sphr	Chir	Hiru	Gast	TOTAL
DC-1				-no data-			ND
NDC-.5-1		145		670			815
SDC-.5-1	18			235			253
NDC-1-1		181		1,051			1,232
SDC-1-1		416		453			869
NDC-2-1	36	72		453			561
SDC-2-1	18	18	18	362			416
NDC-4-1		108		308			416
NDC-7-1		36	18	72			126
SDC-4-1				-no data-			ND
SDC-7-1	18	36		489			543
DC-2	1,522	1,015	507	507	18	54	3,623
NDC-.25-1	1,305	235	852	1,087		18	3,497
SDC-.25-1	1,722	1,450	979	2,501	54	18	6,724
NDC-.5-2	181	2,012	326	217			2,736
SDC-.5-2	181	1,087	217	290	36	18	1,829
NDC-1-2	90	489	290	924			1,793
SDC-1-2	1,541	5,275	1,323	1,051	18	36	9,244
NDC-2-2	90	833	181	145			1,249
SDC-2-2	145	1,667	181	271	145	36	2,445
NDC-4-2	36	36		72			144
NDC-7-2	72	997	54	163	18		1,304
NDC-7-3	779	54	54	54			941
SDC-4-2	108	707	90	217	308	18	1,448
SDC-7-2	18	652	36	145	18		869
SDC-7-3	525	18	199	145		36	923
DC-3	670	326	18	18			1,032
NDC-.5-3	145	6,037	924	126		54	7,285
SDC-.5-3	1,831	616	90	36			2,573
NDC-2-3	2,520	2,538	235			18	5,311
SDC-2-3		1,522	18	36			1,576
DC-4	4,496	8,847	670		36	290	14,339
NDC-1-3	2,175	181	380	72			2,808
SDC-1-3	1,323	199	253			18	1,793
NDC-4-3	1,323	253	54	54			1,684
NDC-7-4	2,320	1,069	181		54		3,624
SDC-4-3	4,550	5,239	2,810	90	72	145	12,906
SDC-7-4	3,100	10,533	924	36	18		14,611
DC-5	10,606	2,973	4,079			145	17,803
NDC-2-4	20,631	6,925	2,284	54		18	29,912
SDC-2-4	8,539	4,514	2,066	18		18	15,155
NDC-7-5	8,212	1,178	3,988	54		90	13,522
SDC-7-5	2,139	6,508	1,414	90	18	72	10,241
SDC-4-4	4,097	6,581	2,375	18		72	13,143
DC-6				-no data-			ND
NDC-4-4	10,424	6,254	3,063	72			19,813

Table 42. Numbers/m^2 of benthic macrofauna by major taxa in September, 1971. Data are based on one sample per station. The conversion factor for original counts is 18.13. (See Table 38 for legend)

Station	Amph	Olig	Sphr	Chir	Hiru	Gast	TOTAL
DC-1				-no data-			ND
NDC-.5-1		924	72	163			1,159
SDC-.5-1		1,269	90	290	54		1,703
NDC-1-1		453		181			634
SDC-1-1		181		634			815
NDC-2-1				290			290
SDC-2-1	18	18		163	18		217
NDC-4-1	18	18	18	235			289
NDC-7-1				72			72
SDC-4-1	18	18		145			181
SDC-7-1				199		18	217
DC-2	1,504	1,722	398	398	90	18	4,130
NDC-.25-1	1,142	2,084	435	435	235	36	4,367
SDC-.25-1	1,250	1,740	580	507	271		4,348
NDC-.5-2	36	2,538	525	199	18	18	3,334
SDC-.5-2	126	2,139	471	145	72	18	2,971
NDC-1-2	416	580	235	344		18	1,593
SDC-1-2	1,087	4,351	1,341	398	199	145	7,521
NDC-2-2	181	308	18	199			706
SDC-2-2	145	1,976	416	126	90	72	2,825
NDC-4-2	72	108		145	18		343
NDC-7-2	18	217	36	72			343
NDC-7-3	1,450	6,073	1,069	235	72	54	8,953
SDC-4-2	108	2,103	253	181	36	36	2,717
SDC-7-2		670	72	181	18		941
SDC-7-3	145	797	90	562			1,594
DC-3				-no data-			ND
NDC-.5-3	4,206	1,269	471	380		36	6,362
SDC-.5-3	1,667	5,094	1,015	562	54	18	8,410
NDC-2-3	743	290	54	290			1,377
SDC-2-3	1,976	2,356	852	344	36	18	5,582
DC-4	3,571	2,066	1,468	90		18	7,213
NDC-1-3	4,351	5,094	1,414	72	18	36	10,985
SDC-1-3	6,109	5,692	779	36		36	12,652
NDC-4-3	1,577	2,683	290	54		18	4,622
NDC-7-4	6,635	6,744	2,320	145	253	18	16,115
SDC-4-3	6,381	2,773	1,069	90		145	10,458
SDC-7-4	1,559	2,701		181			4,441
DC-5	13,325	8,031	3,372	54			24,782
NDC-2-4	18,601	8,448	979	90		36	28,154
SDC-2-4	6,146	8,013	1,595	90	18		15,862
NDC-7-5	5,602	6,689	1,105	181		36	13,613
SDC-7-5	3,136	6,780	906	108	18	18	10,966
SDC-4-4	6,291	4,768	616	72	36	36	11,819
DC-6	11,494	6,418	3,209	18			21,139
NDC-4-4	8,629	4,260	3,227		36		16,152

Table 43. Numbers/m^2 of benthic macrofauna by major taxa in November, 1971. Data are based on one sample per station. The conversion factor for original counts is 18.13. (See Table 38 for legend)

Station	Amph	Olig	Sphr	Chir	Hiru	Gast	TOTAL
DC-1	18	54		54			126
NDC-.5-1	18	36	18				72
SDC-.5-1		108		36	18		162
NDC-1-1				-no animals-			none
SDC-1-1	18	108		36			162
NDC-2-1		18	36	36			90
SDC-2-1		54		435	54		543
NDC-4-1				-no animals-			none
NDC-7-1				-no data-			ND
SDC-4-1				108	18	18	144
SDC-7-1				-no data-			ND
DC-2		1,269	326	308	18		1,921
NDC-.25-1	18	453	344	308	18	126	1,267
SDC-.25-1	308	2,574	308	344	54	36	3,624
NDC-.5-2	36	308	181	36	18	18	597
SDC-.5-2	108	2,066	108	362	54	54	2,752
NDC-1-2	126	290	1,976	380		90	2,862
SDC-1-2		543	126	72			741
NDC-2-2	54	290	181	253			778
SDC-2-2	90	398	163	271	18	145	1,085
NDC-4-2	18	290		235			543
NDC-7-2				-no data-			ND
NDC-7-3				-no data-			ND
SDC-4-2		199	54	54	18	72	397
SDC-7-2				-no data-			ND
SDC-7-3				-no data-			ND
DC-3		1,541	54	543			2,138
NDC-.5-3	435	14,775	1,939	1,939	181	126	19,395
SDC-.5-3	235	670	145	507		36	1,593
NDC-2-3	271	253	126	72	18		740
SDC-2-3	525	2,338	598	271	72	18	3,822
DC-4	217	8,938	2,284	1,396	271	217	13,323
NDC-1-3	815	4,496	1,450	308	235	72	7,376
SDC-1-3	163	12,147	3,789	1,631	580	398	18,708
NDC-4-3	362	90		54			506
NDC-7-4				-no data-			ND
SDC-4-3	2,918	3,988	1,105	217	18	308	8,554
SDC-7-4				-no data-			ND
DC-5	10,805	6,617	1,269	108	18	145	18,962
NDC-2-4	7,106	3,771	870	18	18	54	11,837
SDC-2-4	4,006	9,119	1,649	271	36	18	15,099
NDC-7-5				-no data-			ND
SDC-7-5				-no data-			ND
SDC-4-4	3,172	7,723	960	108	18	54	12,035
DC-6	8,992	6,925	1,250	18			17,185
NDC-4-4	12,962	6,943	1,976	36			21,917

Table 44. Numbers/m^2 of benthic macrofauna by major taxa in April, 1972. Data are based on one sample per station. The conversion factor for original counts is 18.13. (See Table 38 for legend)

Station	Amph	Olig	Sphr	Chir	Hiru	Gast	TOTAL
DC-1				36			36
NDC-.5-1		18					18
SDC-.5-1	18	362	36	743		18	1,177
NDC-1-1				-no animals-			none
SDC-1-1		18					18
NDC-2-1		36					36
SDC-2-1		108		271			379
NDC-4-1				18			18
NDC-7-1				-no animals-			none
SDC-4-1		54		290			344
SDC-7-1		36		290			326
DC-2	217	2,501	562	707		36	4,023
NDC-.25-1	36	5,547	743	870	54	108	7,378
SDC-.25-1	126	960	235	598			1,919
NDC-.5-2	36	870	489	562		54	2,011
SDC-.5-2	90	1,015	54	326		36	1,521
NDC-1-2		18	181	72		54	325
SDC-1-2	90	2,338	344	634	18		3,424
NDC-2-2	54	308	18	308			688
SDC-2-2	90	362	90	199		54	795
NDC-4-2		36					36
NDC-7-2				-no data-			ND
NDC-7-3		416	543	362	163	18	1,502
SDC-4-2	36	362	126	217		36	777
SDC-7-2	18	217	72	271			578
SDC-7-3	18	145	108	181	18		470
DC-3		489	72	217			778
NDC-.5-3	126	1,649	797	580	54	18	3,224
SDC-.5-3	126	253	90	108	54		631
NDC-2-3	145	2,465	362	580	18	36	3,606
SDC-2-3	72	2,810	852	543			4,277
DC-4	471	7,143	489	380	36	54	8,573
NDC-1-3	181	471	235	36		36	959
SDC-1-3	688	3,879	380	181			5,128
NDC-4-3	36	471	18	36	18		579
NDC-7-4	489	598	108	199		18	1,412
SDC-4-3	398	2,628	2,755	507	36	163	6,487
SDC-7-4	525	416	36	54			1,031
DC-5	4,804	5,892	398	72			11,166
NDC-2-4	7,306	12,890	489	235			20,920
SDC-2-4	1,214	8,104	3,390	398	36	90	13,232
NDC-7-5	1,087	3,571	380	453	54		5,545
SDC-7-5	235	8,321	1,559	598	108	54	10,875
SDC-4-4	1,450	6,309	2,846	90	18	18	10,731
DC-6	6,544	7,578	1,178	72			15,372
NDC-4-4	5,765	11,331	1,323	72			18,491

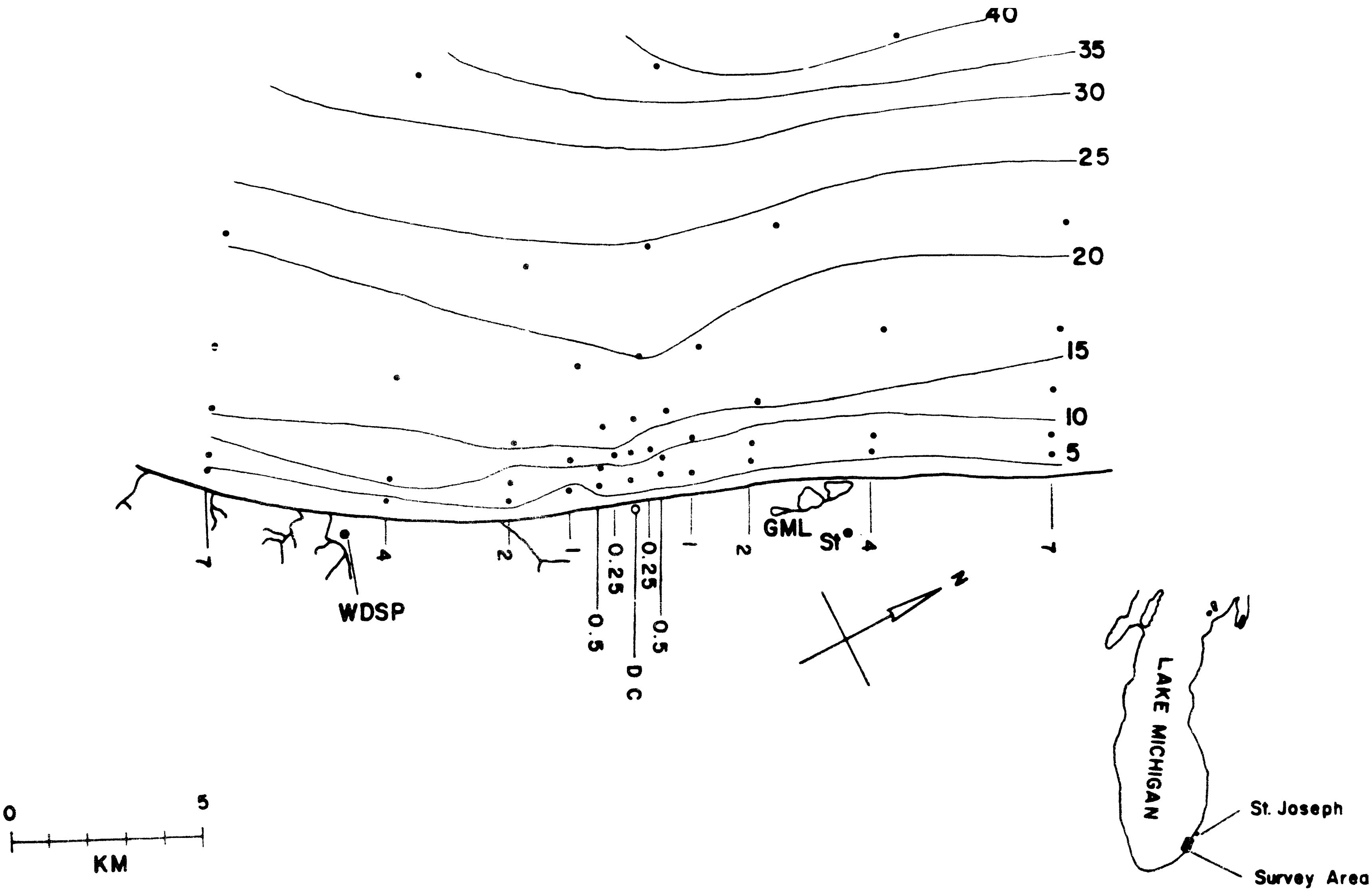


Figure 41. The Donald C. Cook Nuclear Power Plant survey area, 1970-1972. Depth contours in meters. The DC transect is marked at the location of the power plant. Other transects are marked with the distance (in miles) from the DC transect. Dots are station locations in Lake Michiga. WDSP = Warren Dunes State Park; GML = Grand Marais Lakes; St = Stevensville.

Most of the interpretation of the earlier major surveys is presented in Section 2 below, along with information at lower taxonomic levels. Inspection of the data indicates that while variations do occur among the samples from one station in different seasons, and among those from adjacent stations in any one survey, there is considerable similarity among samples from any one month and depth zone. Statistical tests of these observations will be forthcoming.

The stations nearest shore (0 - 8 m) underwent similar changes for the two successive years: April samples had fewest animals, July samples were richest in Chironomidae, and September and November samples yielded more Oligochaeta than did those in other months.

In the depth interval 8 - 16 m, Amphipoda were more numerous in July and September than in April or November. In agreement with observations on 10 July 1970, data given in Part IX, stations in the center of the survey area tended to have larger densities of benthos than those in the north of the survey area (see stations DC-4, NDC-1-3, and SDC-1-3). In addition, stations SDC-7-3, SDC-7-4, and NDC-1-3 each had in excess of 20,000 oligochaetes per m^2 on one occasion, indicating local and perhaps temporary degradation of the sedimentary environment.

The observation in Part IX that the shore zone is generally poor in benthic animals is substantiated by the subsequent data. As noted above, Oligochaeta tend to be locally abundant in the autumn. However, at no time did Amphipoda or Sphaeriidae occur in large populations at depths less than 8 meters, or within a quarter mile of the beach. The Chironomidae are most abundant in this shallow inshore zone and produce the July maximum there.
The July chironomid maximum is due to numerous species which are small enough to escape through the screen during washing, except in summer when they en-

large just before they emerge into adult midges.

Data from two short surveys of May and June 1972 are given in Tables 45 and 46. These data indicate that the increase in Amphipoda, which was noted between the April and July major surveys, occurs between early May and early June. Increases in chironomids and oligochaetes also occur in that month-long period.

These tables, in conjunction with the data from the seasonal surveys, have been used to define depth zones wherein simultaneous changes in sediment composition and composition of the benthos population commonly occur. Abrupt increases in Amphipoda, Sphaeriidae and Oligochaeta occur between 7 and 13 meters, and in Amphipoda and Oligochaeta, again between 22 and 25 meters. These changes correspond to changes in the character of the sediments: in less than 7 meters, coarse and medium sands predominate; between 8 and 22 meters, fine sands with some silt are most frequent; and between 22 and 25 meters, gelatinous silt and clay generally become dominant. Since the zones of changes are somewhat smeared, a certain degree of arbitrary selection has been used and depths of 8, 16, and 24 meters have been chosen as boundaries between zones.

Table 45. Results of short, monthly benthos surveys for May, 1972.

Station	Repl.	Depth (m)	Amph	Olig	Sphr	Chir	Hiru	Gast	TOTAL
DC-X*	a,b,c	1.5	-	-	-	-	-	-	-
DC-1	a	4.6	-	21	21	-	-	-	42
	b		-	42	-	21	-	-	63
	c		-	42	-	-	-	-	42
NDC-.5-1	a	6.5	-	-	-	21	-	-	21
	b		-	-	-	84	-	-	84
	c		-	-	-	125	-	-	125
SDC-.5-1	a	5.0	-	-	-	42	-	-	42
	b		-	-	-	63	-	-	63
	c		-	-	-	21	-	-	21
DC-2	a	14.6	188	3,386	648	334	21	21	4,597
	b		272	1,588	188	585	-	63	2,696
	c		105	2,341	920	732	146	63	4,305
DC-3	a	18.6	-	1,505	1,630	1,756	42	21	4,953
	b		-	125	63	-	21	-	209
	c		-	502	21	167	-	-	690
DC-4	a	22.0	84	293	502	84	-	21	982
	b		42	125	42	21	-	-	230
	c		63	251	439	125	21	21	920
DC-5	a	26.6	7,670	10,847	418	209	21	-	19,165
	b		5,831	7,817	167	125	-	-	13,940
	c		6,897	9,677	418	188	-	42	17,222
DC-6	a	43.7	6,395	8,924	1,568	209	-	21	17,117
	b		6,855	6,186	1,338	230	-	-	14,609
	c		6,897	7,796	1,045	293	-	-	16,030

*Surf zone 100 yards south of harbor entrance, Cook Plant.

Table 46. Results of short, monthly benthos surveys for June, 1972.

Station	Repl.	Depth (m)	Amph	Olig	Sphr	Chir	Hiru	Gast	Other	TOTAL
DC-X	a	1.1	-	-	-	-	21	-	-	21
	b		-	-	-	-	-	-	-	-
	c		42	-	-	21	-	-	-	63
DC-1	a	5.9	42	21	-	105	-	-	-	168
	b		-	251	21	209	-	-	-	481
	c		21	230	63	272	-	-	-	586
NDC-.5-1	a	6.2	-	21	-	690	-	-	-	711
	b		63	63	-	502	-	-	21	649
	c		-	84	-	627	-	-	-	711
SDC-.5-1	a	5.9	-	63	-	167	-	-	-	230
	b		-	84	-	209	-	-	-	293
	c		-	146	42	753	-	-	105	1,046
DC-2	a	13.6	3,887	2,633	1,087	188	105	42	-	7,921
	b		4,201	5,539	961	167	105	146	-	11,119
	c		2,362	857	648	146	21	42	-	4,076
DC-3	a	18.0	2,090	982	21	105	-	21	-	1,129
	b		188	21	21	-	-	-	-	230
	c		272	84	-	84	21	-	-	461
DC-4	a	20.7	4,013	2,633	376	230	21	-	-	7,273
	b		1,547	5,162	564	292	-	21	-	7,587
	c		2,947	6,876	1,442	982	84	209	-	12,540
DC-5	a	25.1	3,741	3,783	397	167	84	-	-	8,172
	b		3,490	3,783	418	146	42	21	-	7,900
	c		9,363	9,342	523	146	21	42	-	19,437
DC-6	a	40.9	7,085	6,124	794	63	-	-	-	14,066
	b		8,548	17,222	4,577	84	42	-	42	30,514
	c		9,844	11,976	3,950	167	-	-	-	25,937

Section 2. Community structure

Prior to the present study, very little information was available about the benthos of shallow sandy bottoms of the Great Lakes. Data on the relative abundance and identity of individual species in this part of Lake Michigan did not exist. Therefore, the task of fundamental description of the benthic community structure had to be added to the central goal of ordinary population assessment. In addition to the simple listing of the species found, it is necessary to attach significance to the species composition of the community, and to the ways in which the community varies within and among depth zones. Species level information can then provide a supplementary means of detecting changes in the benthos, one which may be much more sensitive than simple abundances, and which frequently reveals more about the factors which cause observed changes. We have, therefore, invested great efforts in obtaining species level data, as well as in sorting and counting the numbers of animals.

Figure 41 shows the survey area with station locations and depth contours. The stations considered in this section are the regular systematic survey stations. They range in depth from about 4 to 46 meters, and so include the zone of strongest thermal stratification as it intersects the side of the lake. Sediment types here are graded from coarse sand in the shallow nearshore area to gelatinous silty clay in the deeper reaches. Divers have observed, however, that sediment types do not change smoothly with increasing depth. Patches of silt and dark organic ooze occur in zones which are predominantly clean fine sand.

The existence of gradients and sedimentary heterogeneities should be reflected in the abundance and species composition of the benthos. In this section we describe seasonal variations in benthos species composition, and

then show how the benthic community structure changes with the depth gradient. Since these samples were not replicated at single stations, local sedimentary heterogeneity must be examined in the context of the later sampling design.

Methods

Our standard procedure since the beginning of the benthos surveys has been to collect a single sample, composed of one or two ponar grab hauls, from each station. Each grab haul has a surface area of about 0.06 m^2, so that a factor of 18.13 is used to convert data to the conventional base of one square meter. The samples are washed in a funnel-shaped elutriation device which allows rinsing of the animals and lighter sediments over onto a 0.5 mm screen. Residues of sand and coarser materials are discarded. Particles and animals smaller than 0.5 mm in their least dimension are partially lost through the screen, but smaller animals are often retained, while active and elastic oligochaetes somewhat larger than this may escape. The residue on the screen is washed into a sample bottle and preserved with buffered formalin. In the laboratory, samples are sorted under strong light against a black background, usually without magnification. Oligochaeta and smaller Chironomidae are mounted on slides and identified at high magnification. Mr. D. Klemm of the University of Michigan Museum of Zoology identified representative leeches, but available taxonomic keys were used to identify the other animals.

Species diversity indices for July 1970 data were calculated by the method of Shannon and Weaver[1]:

$$d = -\Sigma(n_i/n)\log_2 n_i/n$$

[1]Shannon, C. E. and W. Weaver. 1963. The mathematical theory of communication. University of Illinois Press, Urbana. 117 p.

where n_i/n is the percent of the population represented by each species in the population.

Results

In order to present species data meaningfully, we must divide them into several categories. First is the group of species which have been picked from sieve residues routinely since the first survey (Table 47). Second is a group of species which can be picked from samples taken by standard procedures, but which for one reason or another have not been picked consistently (Table 48a). Third come those animals which occur in the residues, but are not strictly benthic, i. e. they were captured in midwater as the grab descended (Table 48b). Finally, there are some benthos which are small enough to escape very easily through the washing screen, but which are frequently seen in the residue (Table 48c). Beginning with the samples taken in August 1972, all animals in Table 48a will be picked consistently. Some of these, such as the Naididae and Platyhelminthes, are common in the samples, but others have not been seen in benthos samples simply because they are so rare. Species diversity indices are based only on species listed in Table 47.

Many species remain to be identified, but progress has been made since Part IX. *Pisidium* species are still not distinguished, and the species in Gastropoda genera have not been named. A number of Chironomidae have been reared, but not all reared specimens have been examined. The abbreviations "cf" and "-gr." in Chironomidae names refer to the uncertainty of larval-stage identifications. The former means "near," and is used when a distinctive larva is known to correspond to a certain adult species. Since more than

Table 47. Species of benthos in selected samples from the major surveys. $\bar{x}/m^2$ = mean density over all samples for each month; freq. = frequency, or fraction of the samples in which a species occurred each month; n = the number of samples analysed in each month. Two ponars were combined as a single sample for July and November, 1970; one ponar was used for April and July, 1971.

Species	Jul, 1970 n = 25 $\bar{x}/m^2$	Jul, 1970 freq.	Nov, 1970 n = 35 $\bar{x}/m^2$	Nov, 1970 freq.	Apr, 1971 n = 42 $\bar{x}/m^2$	Apr, 1971 freq.	Jul, 1971 n = 38 $\bar{x}/m^2$	Jul, 1971 freq.
Amphipoda								
Pontoporeia affinis	1762.0	0.84	1344.0	0.94	1232.0	0.70	2560.0	0.87
Oligochaeta Lumbriculidae								
Stylodrilus heringianus	522.0	0.60	376.0	0.63	806.0	0.60	784.0	0.42
Oligochaeta Tubificidae								
Limnodrilus hoffmeisteri[1]	267.0	0.80	337.0	0.77	163.0	0.68	1060.0	0.87
L. angustipenis[1]	12.0	0.28	29.0	0.17	19.0	0.28	94.0	0.37
L. cervix[1]	8.0	0.20	181.0	0.20	4.0	0.08	12.0	0.13
L. profundicola[1]	3.0	0.20	2.0	0.03	3.0	0.15	37.0	0.34
L. claparedeanus[1]	-	-	-	-	0.5	0.03	5.0	0.08
Potamothrix moldaviensis[1]	27.0	0.36	101.0	0.69	28.0	0.45	185.0	0.71
P. vejdovskyi	0.7	0.04	74.0	0.29	5.0	0.08	63.0	0.34
Peloscolex freyi[1]	31.0	0.48	31.0	0.31	3.0	0.10	134.0	0.45
P. variegatus	0.4	0.04	-	-	-	-	-	-
P. multisetosus	-	-	0.5	0.06	-	-	-	-
Tubifex tubifex[2]	-	-	3.0	0.06	19.0	0.18	44.0	0.21
Aulodrilus americanus	3.0	0.08	12.0	0.11	-	-	2.0	0.03
A. pluriseta	-	-	70.0	0.06	-	-	2.0	0.03
immatures w/o hair setae	218.0	0.80	1239.0	0.97	587.0	0.88	595.0	0.89
immatures w/hair setae	6.0	0.08	478.0	0.40	48.0	0.25	69.0	0.21

Table 47 cont'd.

Species	Jul, 1970 n = 25 $\bar{x}/m^2$	freq.	Nov, 1970 n = 35 $\bar{x}/m^2$	freq.	Apr, 1971 n = 42 $\bar{x}/m^2$	freq.	Jul, 1971 n = 38 $\bar{x}/m^2$	freq.
Hirudinea								
Helobdella stagnalis	22.0	0.40	18.0	0.54	9.0	0.10	10.0	0.26
Glossiphonia complanata	0.4	0.04	0.3	0.03	-	-	-	-
Nephelopsis obscura	-	-	0.8	0.9	-	-	0.5	0.03
other Hirudinea	-	-	0.5	0.03	-	-	0.5	0.03
Pelecypoda Sphaeriidae								
Sphaerium striatinum	26.0	0.56	25.0	0.60	16.0	0.33	18.0	0.29
S. nitidum	147.0	0.48	139.0	0.54	106.0	0.30	137.0	0.42
S. transversum	2.0	0.12	1.0	0.11	-	-	-	-
S. securis	-	-	-	-	-	-	1.0	0.05
Pisidium spp.	302.0	0.80	1013.0	0.91	446.0	0.78	615.0	0.82
Gastropoda								
Lymnaea spp.	0.7	0.08	6.0	0.26	3.0	0.10	23.0	0.39
Valvata sp.	1.4	0.12	22.0	0.40	12.0	0.28	2.0	0.11
Bulimus sp.	-	-	-	-	-	-	0.5	0.03
Insecta Diptera Chironomidae								
Chironomus fluviatilis-gr.	18.0	0.60	50.0	0.60	15.0	0.28	110.0	0.42
C. anthracinus-gr.	14.0	0.32	58.0	0.26	10.0	0.15	68.0	0.39
Kiefferulus sp.	2.0	0.20	3.0	0.09	-	-	-	-
Cryptochironomus sp. 1	0.4	0.04	-	-	-	-	-	-
C. sp. 2	38.0	0.64	49.0	0.54	31.0	0.40	30.0	0.45
C. sp. 3	-	-	2.0	0.17	0.5	0.03	1.0	0.08

Table 47 cont'd.

Species	Jul, 1970 n = 25 $\bar{x}/m^2$	freq.	Nov, 1970 n = 35 $\bar{x}/m^2$	freq.	Apr, 1971 n = 42 $\bar{x}/m^2$	freq.	Jul, 1971 n = 38 $\bar{x}/m^2$	freq.
Paracladopelma cf. *obscura*	6.0	0.32	-	-	9.0	0.20	21.0	0.53
P. nereis	32.0	0.32	0.8	0.03	-	-	36.0	0.32
Parachironomus cf. *demeijerei*	6.0	0.28	-	-	-	-	31.0	0.24
Harnischia sp.	-	-	-	-	-	-	0.5	0.03
Polypedilum cf. *scalaenum*	7.0	0.28	0.8	0.03	-	-	36.0	0.32
P. fallax-gr.	0.4	0.04	-	-	-	-	-	-
Tanytarsini spp.	0.4	0.04	0.8	0.06	-	-	10.0	0.24
Heterotrissocladius cf. *subpilosus*	0.7	0.04	2.0	0.06	13.0	0.05	2.0	0.03
H. cf. *grimshawi*	-	-	0.3	0.03	4.0	0.08	3.0	0.05
Psectrocladius cf. *simulans*	-	-	-	-	-	-	1.0	0.03
Monodiamesa cf. *bathyphila*	1.4	0.16	18.0	0.46	9.0	0.25	5.0	0.11
Potthastia cf. *longimanus*	-	-	7.0	0.31	7.0	0.25	-	-
Procladius sp.	40.0	0.44	211.0	0.63	33.0	0.45	2.0	0.11
Number of species	34		36		27		40	

[1]Species of Tubificidae whose immatures are combined in the category "immatures w/o hair setae."

[2]Species whose immatures are combined in the category "immatures w/hair setae." *Ilyodrilus templetoni* may also contribute to this group (see Table 2-2a).

Table 48 . Other invertebrates from benthos samples.

a) Species which were not picked quantitatively from Ponar grab samples before July, 1971.

Gammarus sp. (Amphipoda)

Ilyodrilus templetoni (Tubificidae, Oligochaete)

Trichoptera sp.

Naididae in July, 1971 samples	$\bar{x}/m^2$	freq.
Chaetogaster sp.	81.0	0.63
Uncinais uncinata	28.0	0.18
Nais pardalis	20.0	0.21
Nais sp.	2.0	0.03
Pristina longiseta	0.5	0.03

Hydra sp. (Coelenterata)

Platyhelminthes sp.

Eurycercus lamellatus (Cladocera)

Hydracarina sp.

b) Species which are not endobenthic, but occur often in Ponar grab samples.

Mysis relicta (see part 5, below)

Limnocalanus macrurus (Copepoda)

Leptodora kindtii (Cladocera)

c) Species which are too small to be retained quantitatively in our 0.5 mm-mesh sieve.

Nematoda spp.

Harpacticoidea sp. (Copepoda)

Ostracoda spp.

one species has frequently been reared from a single larval type, the identification cannot be considered positive. The latter refers to a larval type which is known to correspond to several adult species. Different larval types of the genus *Chironomus* are taken here to indicate distinct adult species when they occur together. The system of generic nomenclature is that proposed by Hamilton, Saether, and Oliver.[1]

The species *Chironomus attenuatus* and *C. anthracinus* have been reared from anthracinus -gr. larvae. *Paracladopelma nereis* was identified from reared adults. *Procladius culiciformis* has been identified from reared larvae, but it is possible that other species of this genus are also numerous, for larval differences are minor. *Polypedilum*, *Cryptochironomus*, Tanytarsini, and other *Chironomus* species have been reared, but not yet identified.

The relative abundances over the entire survey for dominant taxa are given in Table 49. In July 1970 and 1971, and in April 1971, *Pontoporeia* was the most abundant animal. This species mates in midwinter, but females carry their young until late May or early June, at least at depths less than 22 meters. Just after the young are released, the population reaches a maximum. Deeper than 22 meters, seasonal differences in size and maturity of *Pontoporeia* become less distinct, as do differences in abundance.

The oligochaete *Stylodrilus heringianus* was most abundant in April. The proportion of mature individuals was about 60% in April and July 1971, but less than 40% in November 1970. Perhaps these worms have an annual average life cycle in which adults reproduce in summer and decline in autumn, while the winter is spent in growth and maturation. The cycle is not distinct, however, because large portions of both mature and immature worms are always present. The strongest feature of the seasonal changes is the population

1 Hamilton, A. L., D. A. Saether, and D. R. Oliver. 1970. Tech. Report Fish. Res. Bd. Canada 124.

Table 49. Contribution of dominant taxa to the benthos community.

	% of Total Fauna			
	Jul 1970	Nov 1970	Apr 1971	Jul 1971
Pontoporeia affinis	49.9	22.8	33.8	37.6
Stylodrilus heringianus	14.8	6.7	22.1	11.5
Tubificidae	16.3	43.3	24.2	33.8
Sphaerium nitidum	4.2	2.4	2.9	2.0
Pisidium spp.	8.6	17.2	12.2	9.0
Chironomidae	4.7	6.8	3.6	5.2
Remainder	1.5	0.8	1.2	0.9
Total $\#/m^2$	3528	5906	3641	6810

minimum in November. Tubificidae are composed predominantly of *Limnodrilus hoffmeisteri*, with moderate numbers of *Potamothrix moldoviensis*, *P. vejdovskyi*, and *Peloscolex freyi*. *L. hoffmeisteri* is cosmopolitan, and the other three species are associated with moderate enrichment, such as occurs in parts of Green Bay and the central basin of Lake Erie. This species association indicates some enrichment, but not serious pollution of the survey area. On the other hand, a few samples have contained large numbers of Tubificidae ($>10{,}000/m^2$) with important proportions of *Limnodrilus cervix*, and *Tubifex tubifex*. The stations at which such samples were taken did not have such high densities in other surveys, so it appears that local pockets of highly organic mud occur irregularly over middle depths in the survey area. Examples are SDC-7-3 in November 1970; SDC-7-4 and DC-4 in July 1971; and, to a lesser degree, NDC-2-3 in November 1970.

Sphaerium nitidum is a cold stenothermal species which is almost completely restricted to depths between 18 and 33 meters. Its numbers vary little from season to season.

Pisidium species as a group were low in relative and absolute abundance in the two Julys and highest in November 1970. This evidently represents autumn reproduction. Yet it may be attributable to only one or two of the more numerous *Pisidium* species.

Chironomidae are clearly the most seasonal of the major taxa. Some species occur in much larger quantities, or exclusively, in July: *Paracladopelma nereis* and *Parachironomus* cf. *demeijerei*, small species restricted to depths less than 8 meters; *Polypedilum* cf. *scalaenum*; and *Paracladopelma obscura*. These species are emerging during July samples, so those which have already left the lake are never seen in major surveys. Other species evidently emerge after April, and are present mainly in November and April samples: *Monodia-*

mesa cf. *bathyphila* and *Potthastia* cf. *longimanus*. A few larger species occur all year, either because the smaller instars are retained in the sieve, or because the small stages are passed in a very short time, and the length of the fourth and last larval instar constitutes most of an animal's life-span. These species emerge from July to October: *Chironomus* spp., *Cryptochironomus* sp. 2, and *Procladius* spp.

The Chironomidae, along with Tubificidae and *Pisidium*, were much more numerous in July 1971 than in July 1970 (Table 50, and Figures 42 and 43). The increases in Tubificidae were spread evenly over the species. Changes in Chironomidae could be partly due to later timing of the survey date in the emergence period of some species, but the increases in *Chironomus* and Tanytarsini species probably represent real changes in population size. *Procladius*, in contrast, was less numerous in July 1971. The kinds of species which increased as a group indicate that a generally beneficial increase in the food supply to benthos occurred in July 1971.

The most numerous genera of Chironomidae are interestingly, those characteristic of typical eutrophic lakes: *Chironomus*, *Cryptochironomus*, *Polypedilum*, and *Procladius*. These co-occur with small numbers of forms generally found in oligotrophic lakes: Tanytarsini, *Heterotrissocladius*, *Monodiamesa*, *Potthastia*, and *Paracladopelma* cf. *obscura*. Genera of mesotrophic lakes (*Sergentia/Phaenopsectra*, *Stictochironomus*) are absent, as are species associated with aquatic macrophytes. Two species appear to be especially adapted to frequently disturbed, shallow, sandy bottoms, and have been found rarely or never in North America outside of the Great Lakes: *Paracladopelma nereis* and *Parachironomus* cf. *demeijerei*.

Other taxa account for less than 1.5% of the fauna in all seasons. Because of their size, *Sphaerium striatinum*, the Gastropoda, and *Helobdella*

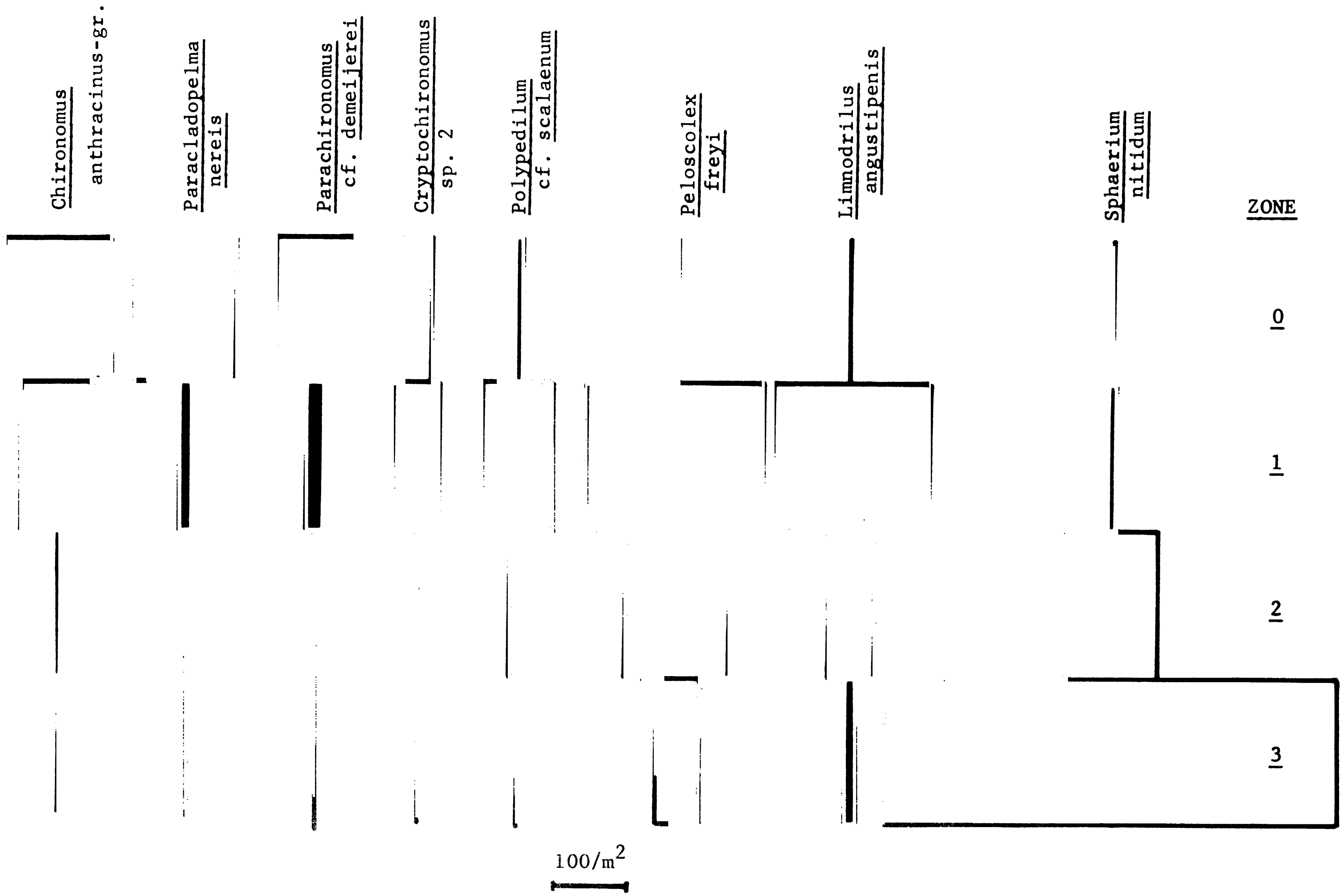


Figure 42. Mean abundances by zones for species of Chironomidae, Oligochaeta, and Sphaeriidae. The scale of numbers per m^2 is shown at the bottom. Zone 0 = 0 - 8 m depth; Zone 1 = 8 - 16 m; Zone 2 = 16 - 24 m; Zone 3 = >24 m. Data from July 1971.

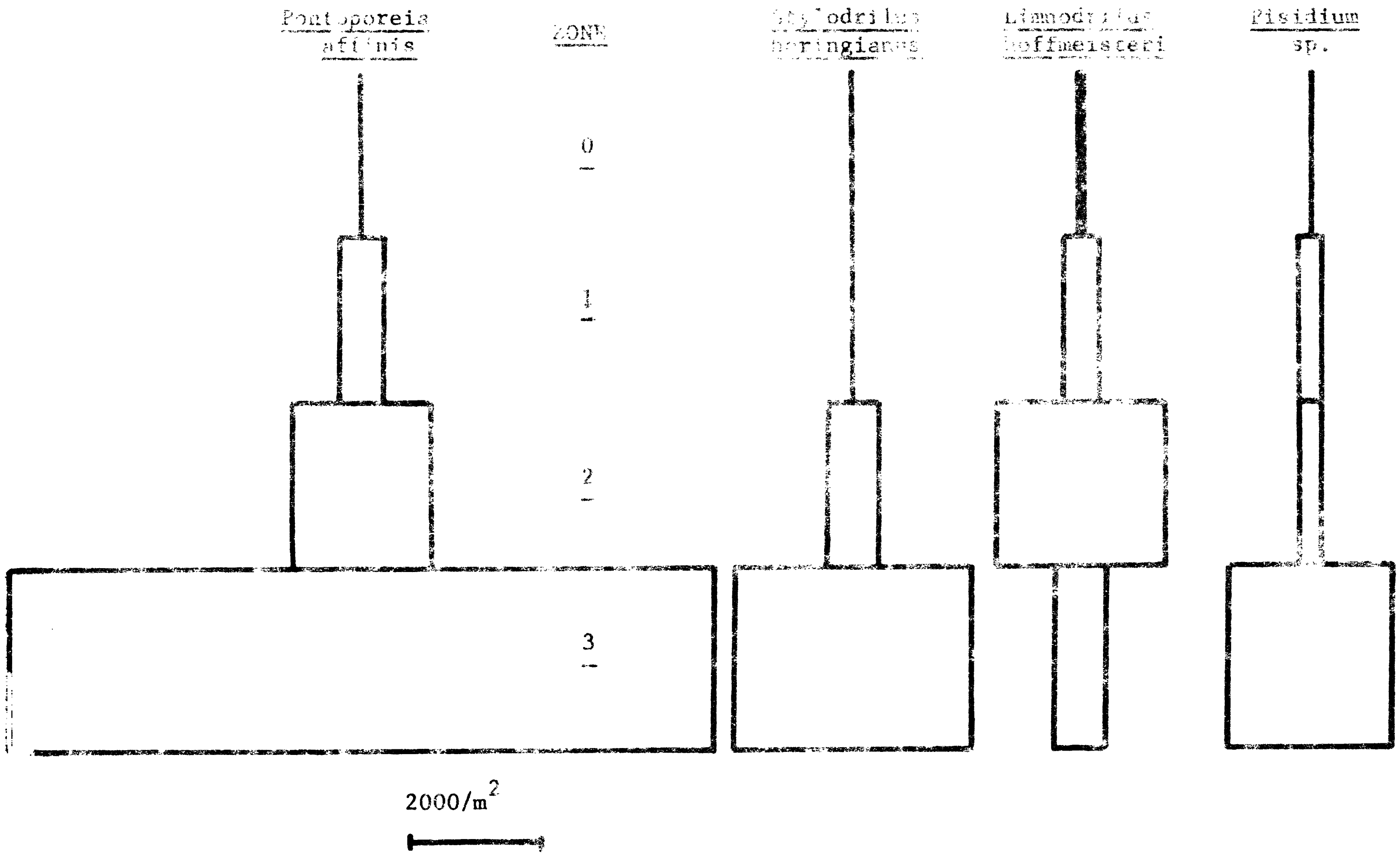


Figure 43. Mean abundance by zones for species of Amphipoda, Oligochaeta, and Sphaeriidae. The scale of numbers per m is shown at the bottom. Zone limits given in Figure 42 legend. Data from July 1971.

stagnalis would appear more important if the data were in biomass form.

The species data support a subdivision of the depth gradient into a series of zones. Depths less than 8 meters (Zone "0") include most of the two small, unusual chironomids and are virtually devoid of Sphaeriidae and *Pontoporeia.* Between 8 and 16 meters (Zone "1"), *Pontoporeia*, Tubificidae, and *Pisidium* become moderately abundant, and *Peloscolex freyi, Limnodrilus angustipenis, Cryptochironomus* sp. 2, *Chironomus* spp., and *Polypedilum* cf. *scalaenum* occur mainly in this zone. Between 16 and 24 meters (Zone "2"), *Pontoporeia* and *Pisidium* reach high abundances, *Stylodrilus* becomes abundant, and *Sphaerium nitidum* occurs almost exclusively. Deeper than 24 meters (Zone "3"), a balance of *Pontoporeia, Stylodrilus,* Tubificidae, *Pisidium*, and probably *Heterotrissocladius* cf. *subpilosus* becomes established, the typical benthos of the Great Lakes' profundal zones.

This pattern of zonation is supported also by seasonal changes in *Pontoporeia* populations (Figure 44).

These distributions are represented in Figures 42 and 43, and Tables 50 through 52. It was on this basis, as well as on the analogous changes in total numbers of benthos, that the stratification of the survey by depth was designed.

Species diversities for July 1970 samples are shown in Figure 45. They show a tendency toward moderately low, consistent diversities near shore, but highly variable diversities farther out. The cases in which diversities were very low offshore were due to very large proportions of *Pontoporeia* in the samples. This suggests that, in the Great Lakes, the usual relationship between low diversity and degredation of the benthic environment is not always valid. Near shore, low diversities are due to the very few species which occur there. The equable distribution of individuals among those species coun-

Table 50. Mean numbers per m^2 by depth zones for dominant species for July, 1970.

Species	0–8m	8–16m	16–24m	>24m
Pontoporeia affinis	2	704	3,455	4,670
Stylodrilus heringianus	0	28	1,255	1,420
Limnodrilus hoffmeisteri (mature)	0	216	506	230
Limnodrilus angustipenis (mature)	0	17	9	28
Peloscolex freyi (mature)	0	30	35	0
Sphaerium nitidum	0	2	426	122
Pisidium spp.	0	172	620	431
Chironomus anthracinus-gr.	5	2	36	13
Cryptochironomus sp. 2	37	71	5	0
Paracladopelma nereis	153	2	0	5
Parachironomus cf. *demeijerei*	24	2	1	0
Polypedilum cf. *scalaenum*	0	17	1	0

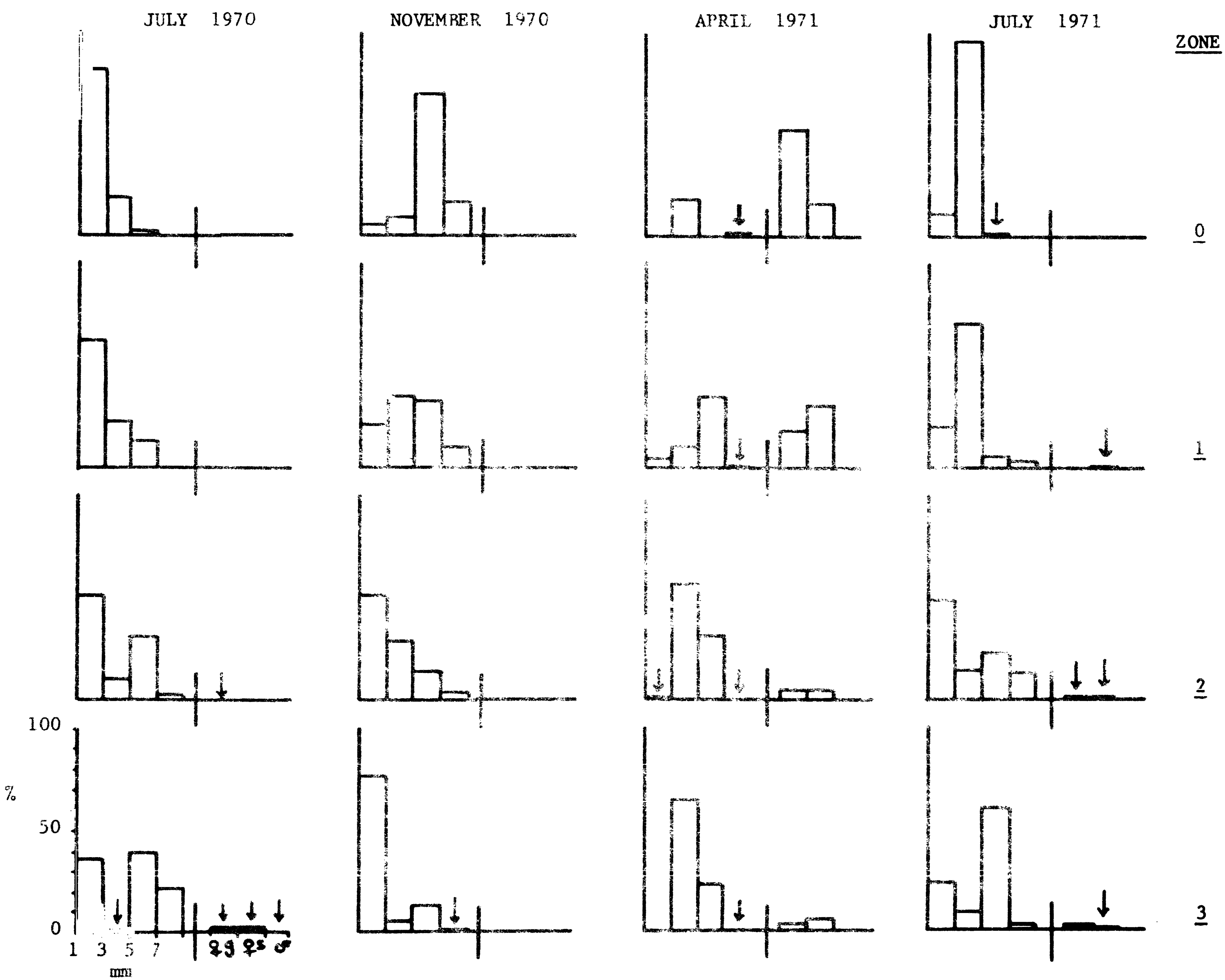
Table 51. Mean numbers per m^2 by depth zones for dominant species for November, 1970.

Species	0-8m	8-16m	16-24m	>24m
Pontoporeia affinis	15	214	1,584	5,345
Stylodrilus heringianus	0	68	360	1,664
Limnodrilus hoffmeisteri (mature)	14	725	164	93
Limnodrilus angustipenis (mature)	0	78	0	0
Peloscolex freyi (mature)	0	53	35	0
Sphaerium nitidum	0	36	384	36
Pisidium spp.	100	985	1,105	1,977
Chironomus anthracinus-gr.	0	140	17	4
Cryptochironomus sp. 2	36	111	3	0
Paracladopelma nereis	5	0	0	0
Parachironomus cf. *demeijerei*	0	0	0	0
Polypedilum cf. *scalaenum*	0	1	0	0

Table 52. Mean numbers per m^2 by depth zone for dominant species for April, 1971.

Species	0-8m	8-16m	16-24m	>24m
Pontoporeia affinis	20	59	1,054	6,756
Stylodrilus heringianus	4	11	892	3,919
Limnodrilus hoffmeisteri (mature)	22	79	284	327
Limnodrilus angustipenis (mature)	6	34	23	15
Peloscolex freyi (mature)	4	2	3	0
Sphaerium nitidum	0	2	261	116
Pisidium spp.	54	238	581	1,373
Chironomus anthracinus-gr.	0	9	22	0
Cryptochironomus sp. 2	17	107	12	0
Paracladopelma nereis	0	0	0	0
Parachironomus cf. *demeijerei*	0	0	0	0
Polypedilum cf. *scalaenum*	0	0	0	0

Figure 44. Percentage of *Pontoporeia affinis* in several size and sex conditions in bottom grab samples from Cook Plant benthos surveys. Each set of axes is based on several combined samples from one survey within the depth zones defined in the text. In the lower left corner the scales and meanings of the axes are shown. The vertical axes are % of total counted in each zone and month. The horizontal axes are size (immatures only, left side of vertical cross-line) and sexual condition (right side of vertical cross-line). The bars of the histograms are for the classes immatures <3 mm, 3-5 mm, 5-7 mm, and >7 mm, and for gravid females (♀ g), spent females (♀ s), and males (♂). The downward-pointing arrows indicate that >0% and ≤2% were found in that class in the corresponding samples.


JULY 1970
NOVEMBER 1970
APRIL 1971
JULY 1971
ZONE
0
1
2
3
100
%
50
0
1
3
5
7
mm

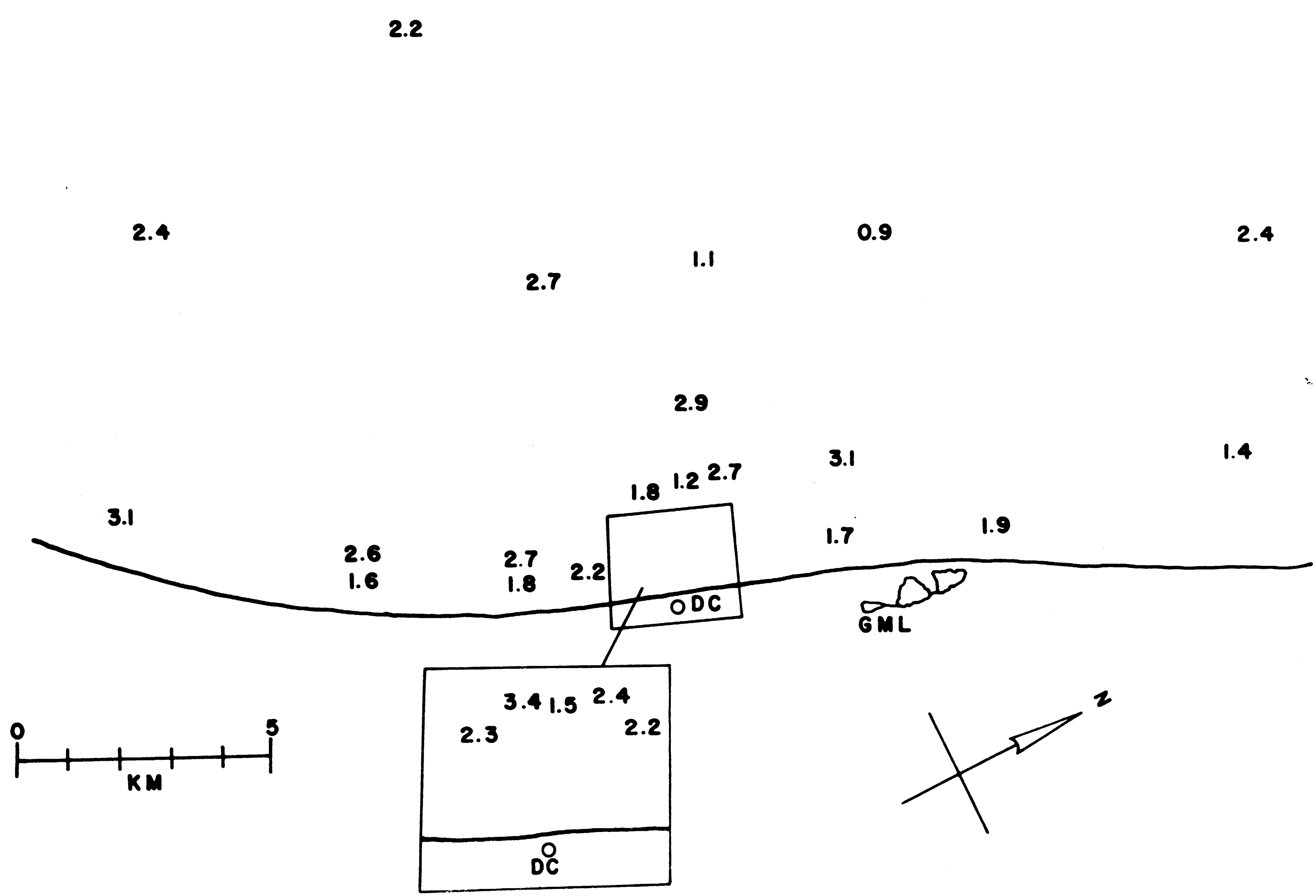


Figure 45. Species diversity indices for samples 0.11 m^2 in surface area in July 1970. Formula for the index is given in the text. DC = sit of Cook Plant. GML = Grand Marais Lakes.

teracts the low number of species to some extent, and increases the index slightly. There is no support for a conclusion that low nearshore diversities are the result of a degraded environment, when the species which occur there are considered. Since the interpretation of species diversity values in this environment is complex, we believe that the use of such indices to detect changes due to plant effects will be difficult, and less reliable than simpler information about the relative and absolute abundances of single species.

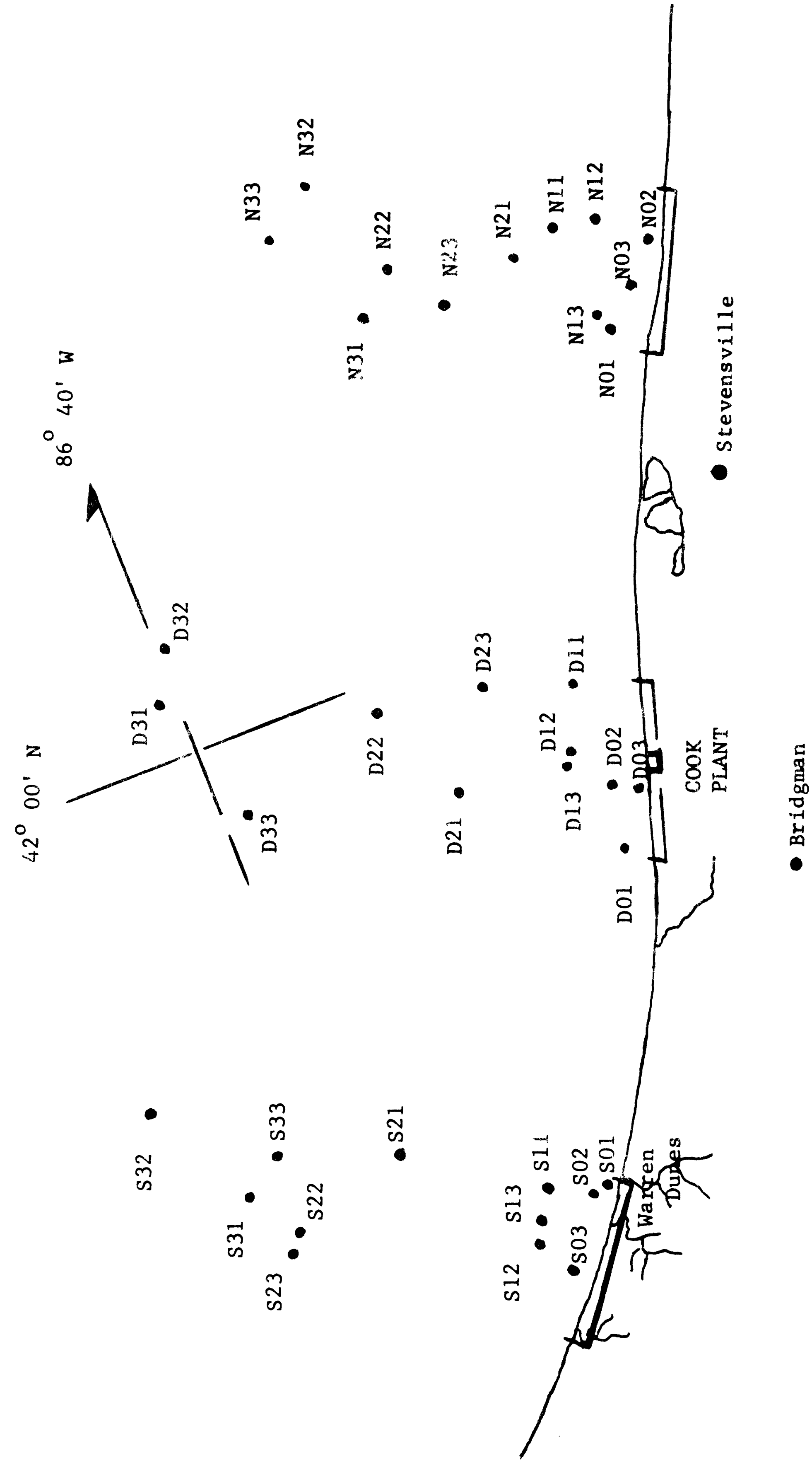
Section 3. Statistical analysis and the stratified random survey plan for benthos, July 1972

If solid proof of ecological change or lack of it in the Cook Plant survey area is to be achieved, adherence to the prerequisites and rules for analysis and interpretation of statistics must be maintained though several complete surveys. The primary goal of the analyses is to develop techniques which will discriminate among benthos communities and populations with the greatest possible sensitivity, and which will make full use of all information that is available. Preliminary data are used mainly to define zones of similar species composition and abundances. Separate analyses within these zones can determine whether or not they are valid. If so, the capacity to detect change will be improved, because the variability will be less at any one time among samples within smaller, more homogeneous biological zones. A sampling plan can then be adopted which meets the design requirements for analysis. The data can then be examined for consistency with the rules concerning frequency distributions and interrelationships among moments of the distribution, and their form adjusted by transformations as necessary. When all statistical prerequisites or assumptions are met, differences among zones within regions, the same zones in different regions, and the same zones in different seasons, or before and after plant operations, can be tested. Levels of statistical confidence about the reality of apparent changes can be provided.

The data presented in Section 2 show that changes in species and abundances occur at approximate depth contours of 8, 16, and 24 meters, and between 30 and 40 meters. This evidence has not been statistically tested, but the sharp discontinuities in tabular data make such conclusions almost foregone. Depth contours, or lines parallel to shore which approximated them

were used to stratify the survey area into faunal zones. To test whether differences existed between the so-called control areas, north and south of the plant site, and the region directly to the front of the plant itself, three regions were arbitrarily defined. One, called "D," is centered on the plant itself, and extends one mile along shore in each direction. The other two are between 5 and 7 miles from the plant; the north region is called "N" and the south region, "S." Each region was stratified by depth as outlined above into the following zones: "0" - beach to 8 m; "1" - 8 to 16 m; "2" - 16 to 24 m; and, "3" - 24 to 35 m. Three random sampling sites are chosen in each of the 12 zones. This is done by defining square areas 100'x 100' in zones 0 and 1, and 200'x 200' in zones 2 and 3. It is assumed that the ship has equal likelihood of being anywhere within the square when the captain is asked to stop at the center of it. The boat drifts somewhat during each station due to wind and currents, and it is deemed reasonable that successive casts are randomly located within the sampling site (square). The navigational charts we use are scaled so that the size of an ordinary pencil dot is almost as large as a 100' x 100' square. Each zone is divided into appropriately sized squares on a coordinate system, and two coordinates are obtained for each sampling site from a table of random numbers. Figure 46 illustrates the pattern of zones and stations. At each sampling site in zone 0, five full-sized ponar grab (0.05 m^2) casts are made. Similarly, three modified ponar grab (0.017 m^2) casts are made at each site in zones 1, 2, and 3. The different numbers and sizes of samples are designed to reduce the variance resulting from low densities of animals and patchy patterns of dispersion in the shallowest area. Offshore, faunal densities are higher, and limitations on the time available to sort the samples required us to reduce the number and surface area of samples. To speed up the analysis, we have

Figure 46. Station locations in the systematic-random benthos survey of July 1972. Regions are indicated as N (north control), D (in front of Cook Plant), and S (south control). Left numeral is the zone number; right number is the sample number. See legend of Figure 42 for zone depth limits. Stations were chosen at random within zones. The bases of the regions are marked off at the shoreline.


N32
N33
N22
N23
N21
N11
N12
N02
N03
N13
N31
N01
Stevensville
86° 40' W
D32
D23
D11
D31
D22
D12
D02
D03
COOK
PLANT
Bridgman
42° 00' N
D33
D13
D21
D01
S32
S33
S21
S11
S02
S01
Warren
Dunes
S13
S31
S22
S03
S23
S12

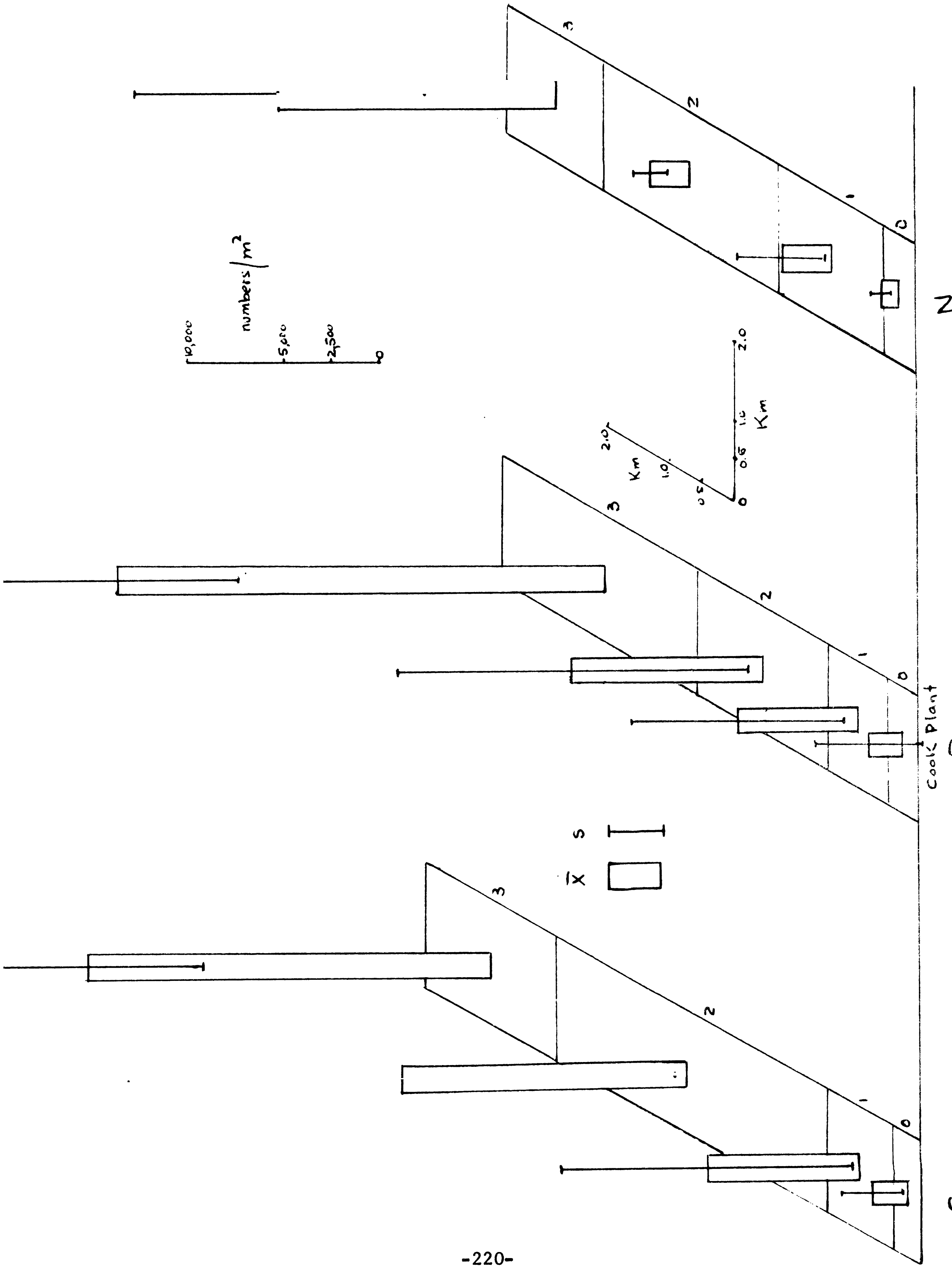
bypassed the double-randomization aspects of the design and assumed that all individual samples from a given square zone were from random casts within the square zone. We intend to test this assumption at a more detailed level in the near future.

The first data from this sampling design were obtained in July 1972. They are presented as zone means for major and some minor taxa in Figures 47 through 58. Standard deviations of the observations are illustrated. It should be noted that these deviations make no assumptions about the distributions of the number of animals per sample, and cannot be used to test for the statistical significance of differences among means. They simply illustrate the variability of samples within zones.

Except for a decline in zone N-2 (16 - 24 m), total animals (Fig. 47) increased in successive zones from shore outward. The standard deviations were approximately the same as the means in each region for zones 0, 1, and 2, but they were much reduced in zones 3. The same basic pattern was true for *Pontoporeia*, *Stylodrilus*, Tubificidae, and *Pisidium*. *Pontoporeia* usually had lower proportional standard deviations, and the standard deviations in zones 3 were not reduced as markedly for the Oligochaeta and *Pisidium*. *Pontoporeia* was relatively abundant in zone N-2, unlike total animals and the other three groups mentioned.

Less abundant taxa had other patterns of distribution. *Sphaerium striatinum* was most abundant in zones 1 (8 - 16 m) and 2 (16 - 24 m), but was weakly represented in the north region. *Sphaerium nitidum* was absent from zones 0 and 1, and was most abundant overall in zones 3. Its relative abundances in zones 2 and 3 were different in different regions, however. The Chironomidae larvae, with the exceptions of *Procladius* and *Monodiamesa* (not shown and never abundant), reached highest densities in zones 0 and 1. Only

Figure 47. Mean number per m^2 of total benthic macrofauna in the 12 zones of the systematic-random survey, July 1977. The line across the bottom is the shoreline, and the zones extend out in the "horizontal" plane (distance scale inset). Zones are labelled with numbers to the right of each. The "vertical" bars are the means (see scale inset) of all replicates and stations in each zone with associated standard deviations. D = Cook Plant region; N = North control region; S = South control region.


numbers/m²
10,000
5,000
2,500
0
Km
2.0
1.0
0.5
0
0.6
Cook Plant
x̄
s
3
2
1
0
N
D
S

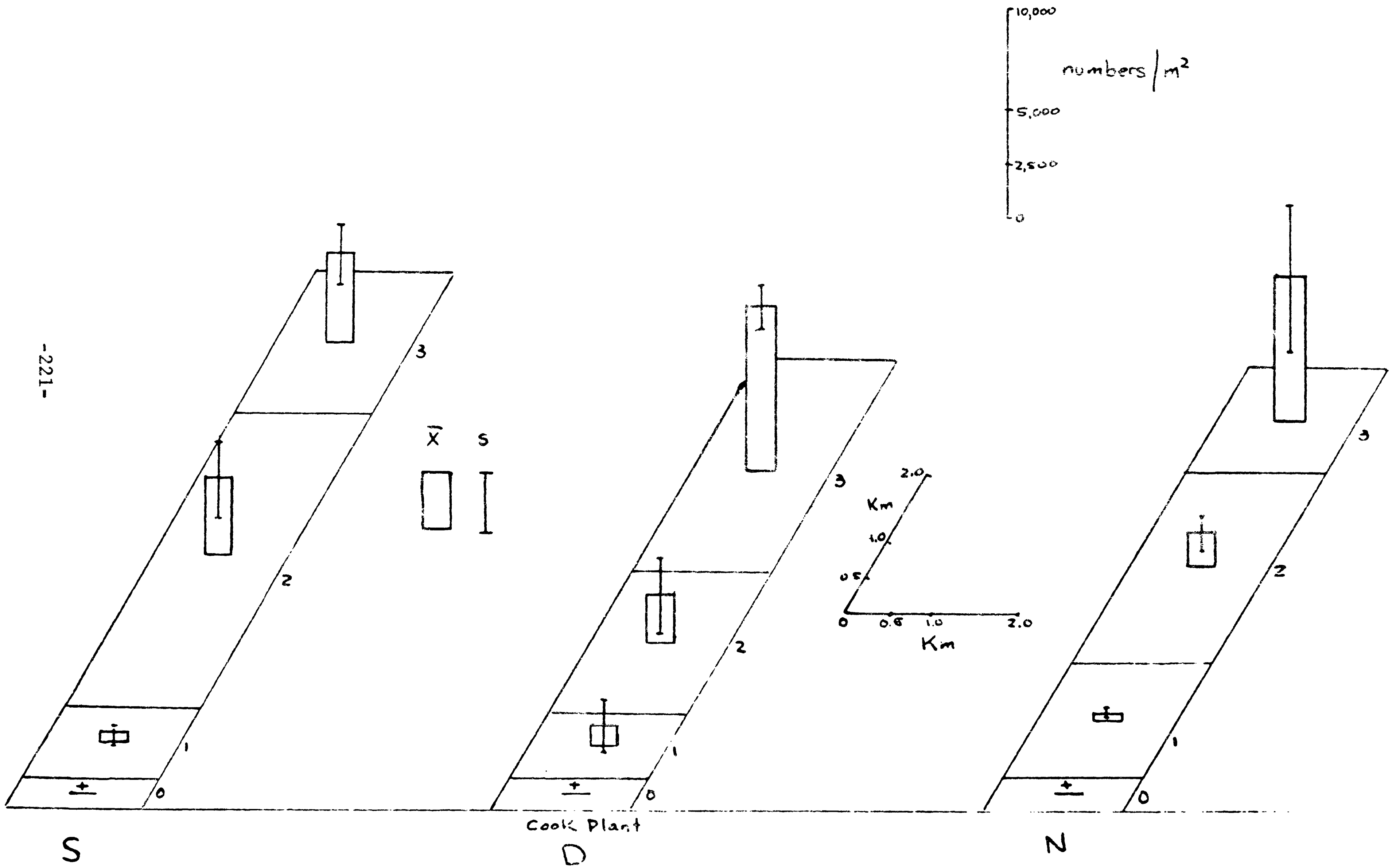


Figure 48. Mean number per m^2 of *Pontoporeia affinis* in the 12 zones of the systematic-random survey, July 1972. See Figure 47 for legend and scales.

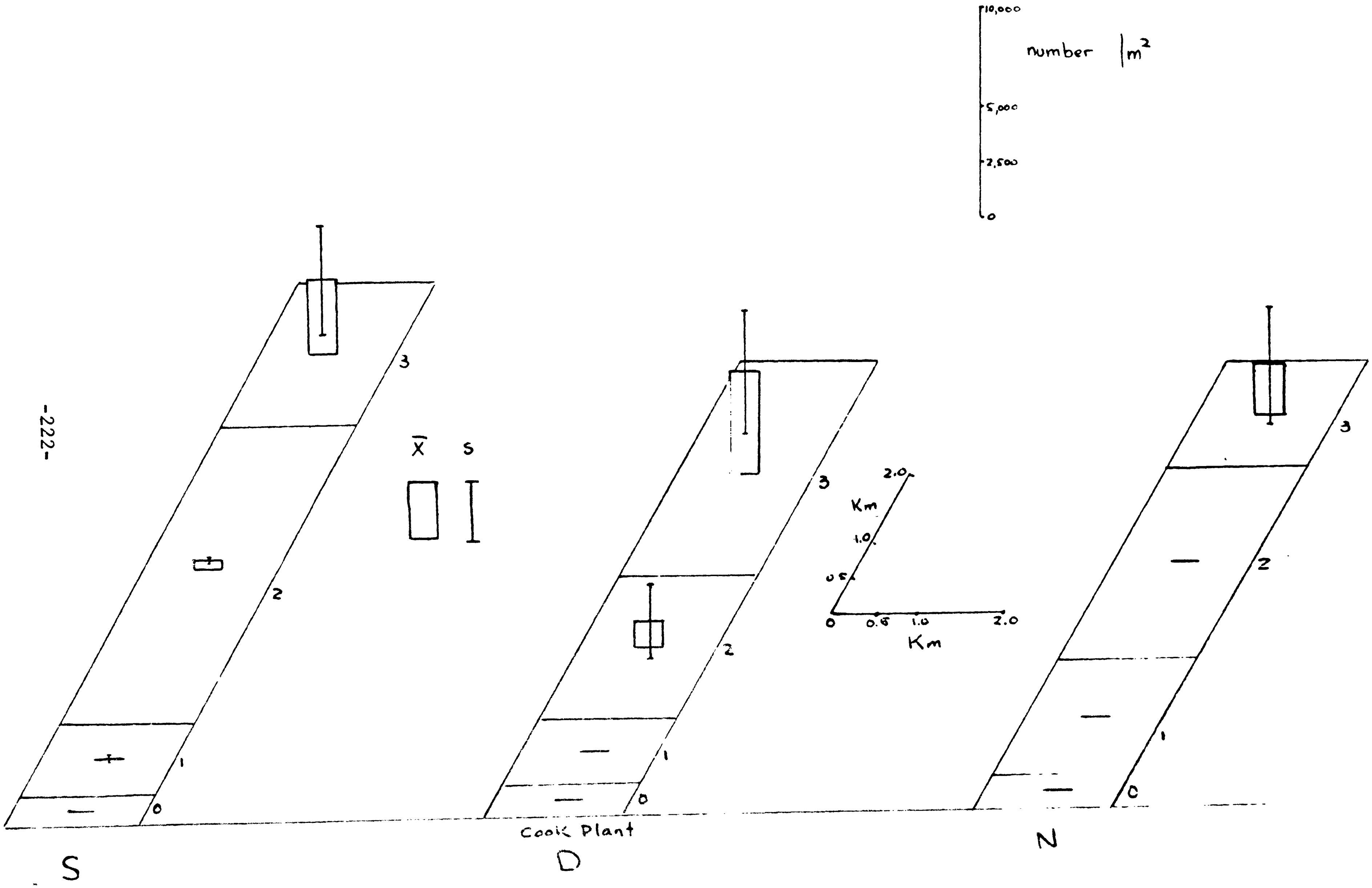


Figure 49. Mean number per m^2 of *Stylodrilus heringianus* in the 12 zones of the systematic-random survey, July 1972. See Figure 47 for legend and scales.

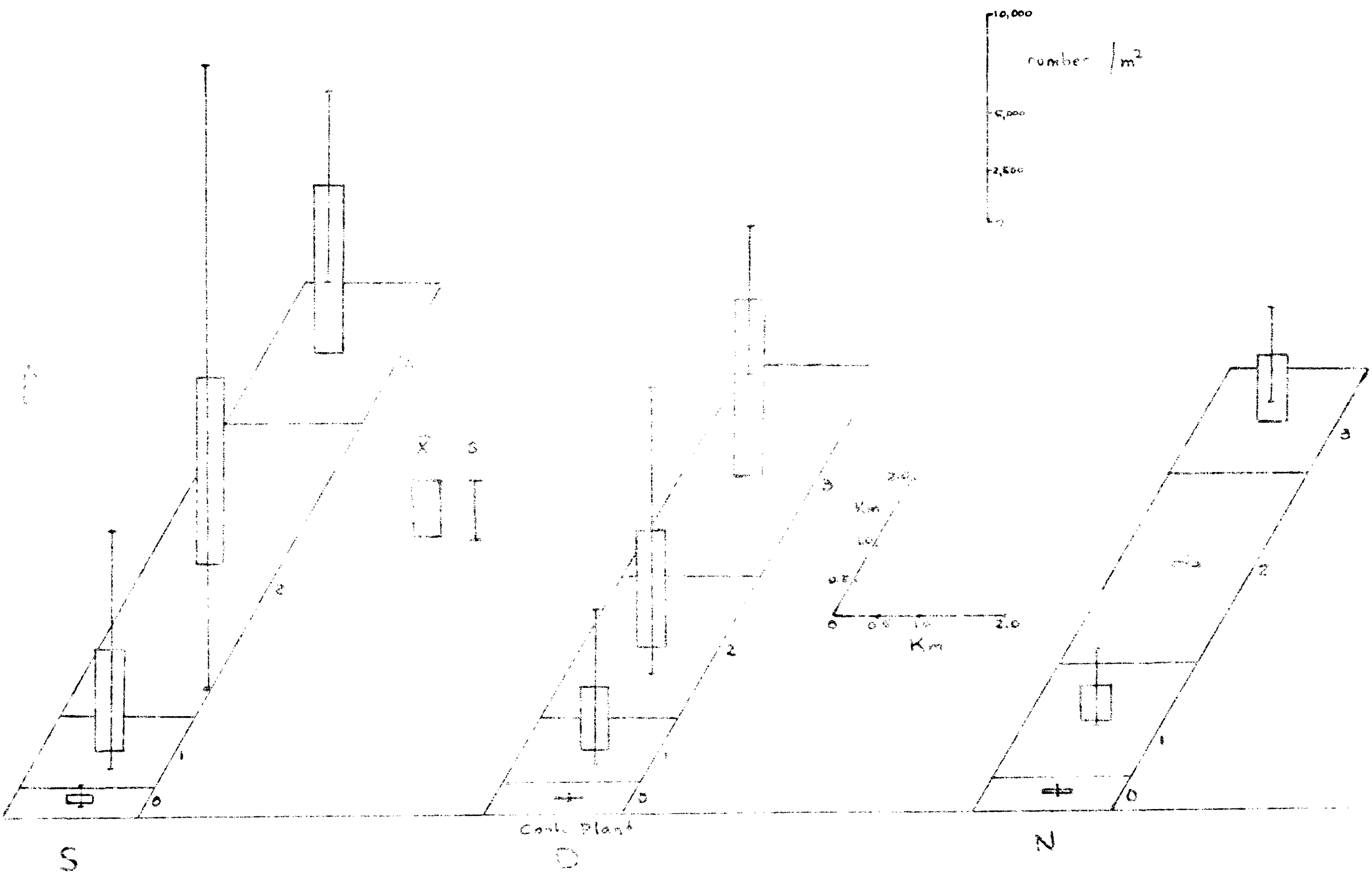


Figure 50. Mean number per m^2 of Total Tubificidae in the 12 zones of the systematic-random survey, July 1972. See Figure 47 for legend and scales.

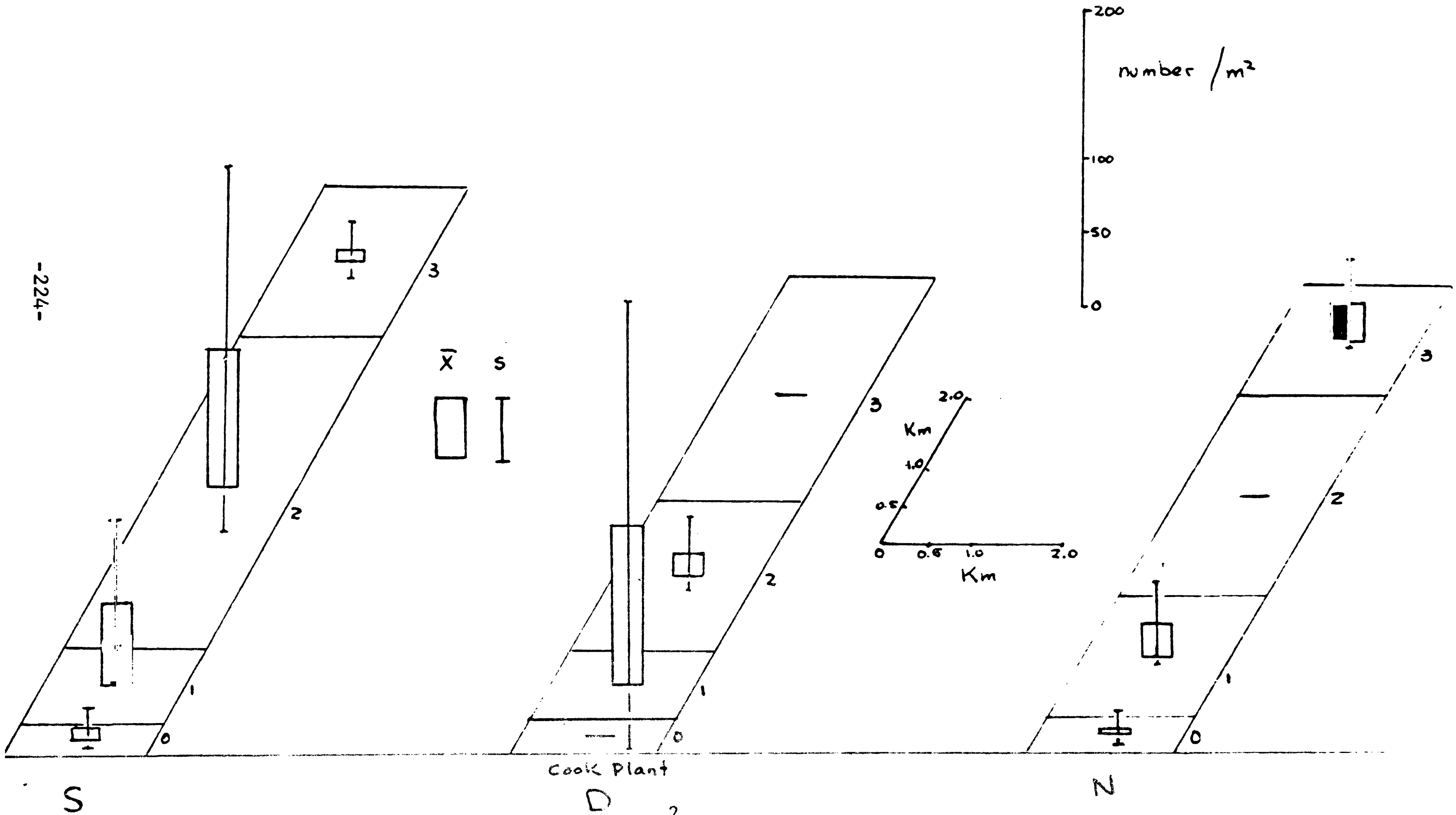


Figure 51. Mean number per m^2 of *Sphaerium striatinum* in the 12 zones of the systematic-random survey, July 1972. The inset scale shows numbers per m^2. See Figure 47 for legend.

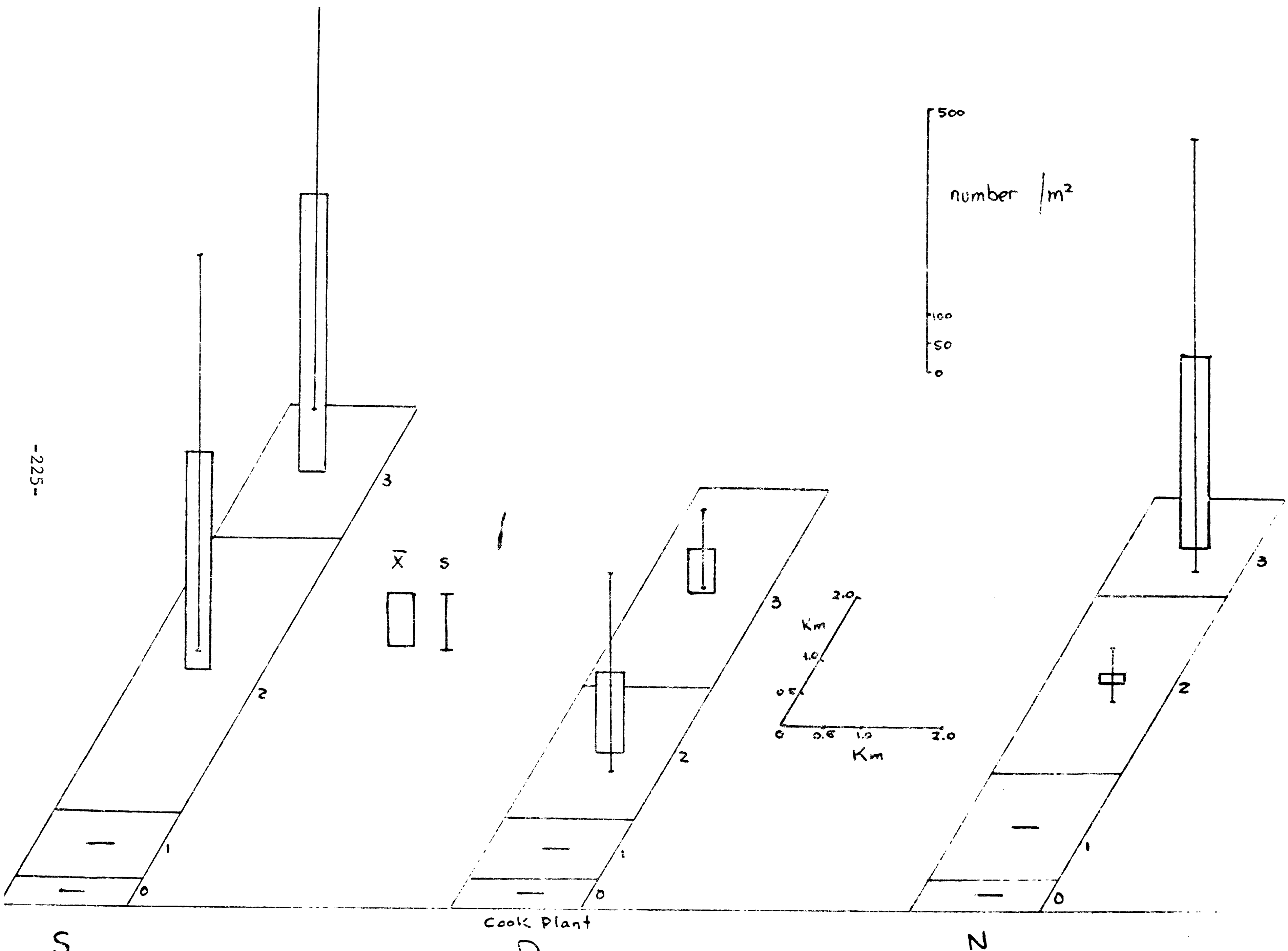


Figure 52. Mean number per m^2 of *Sphaerium nitidum* in the 12 zones of the systematic-random survey, July 1972. The inset scale shows numbers per m^2. See Figure 47 for legend.

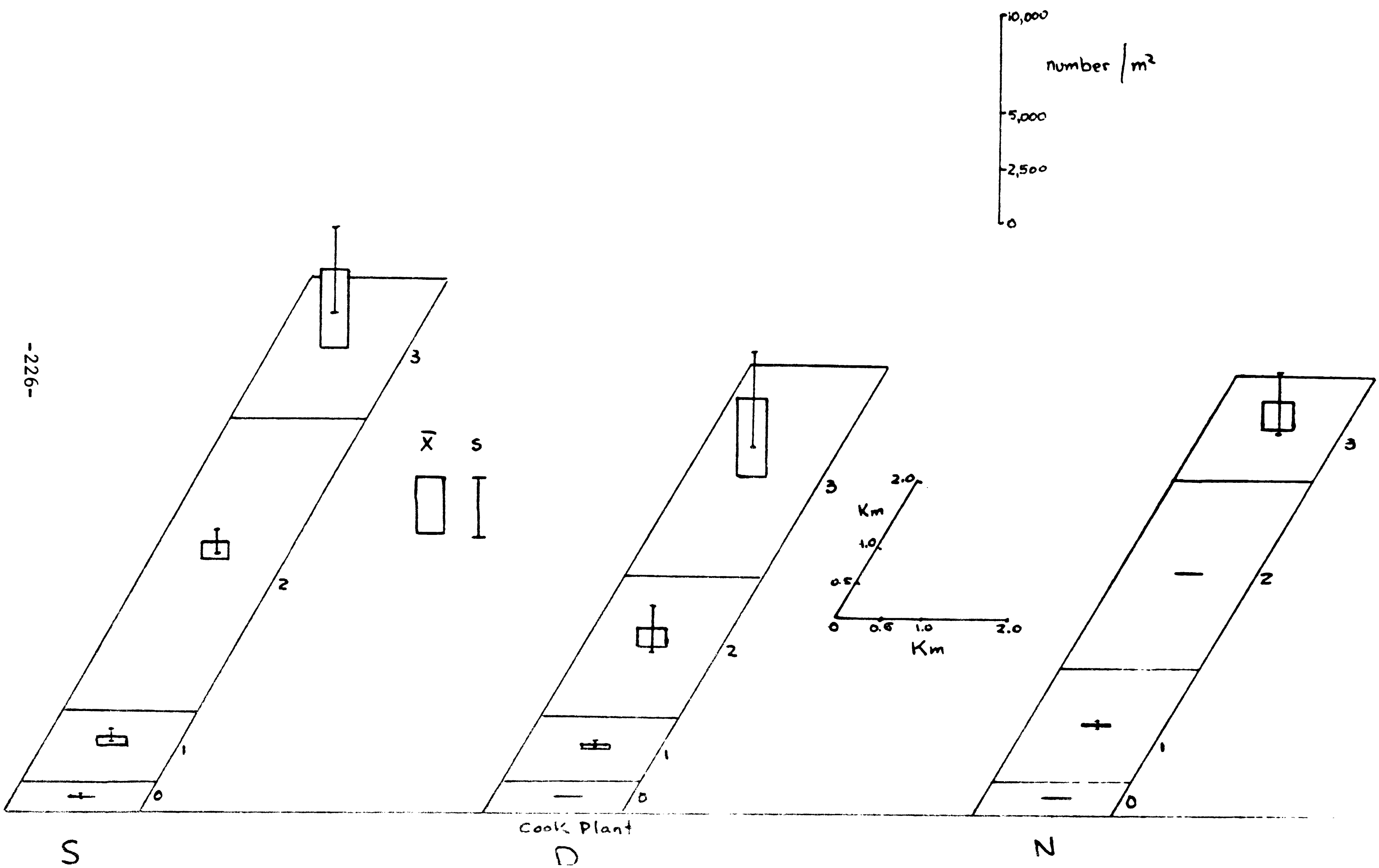


Figure 53. Mean number per m^2 of *Pisidium* spp. in the 12 zones of the systematic-random survey, July 1972. See Figure 47 for legend and scales.

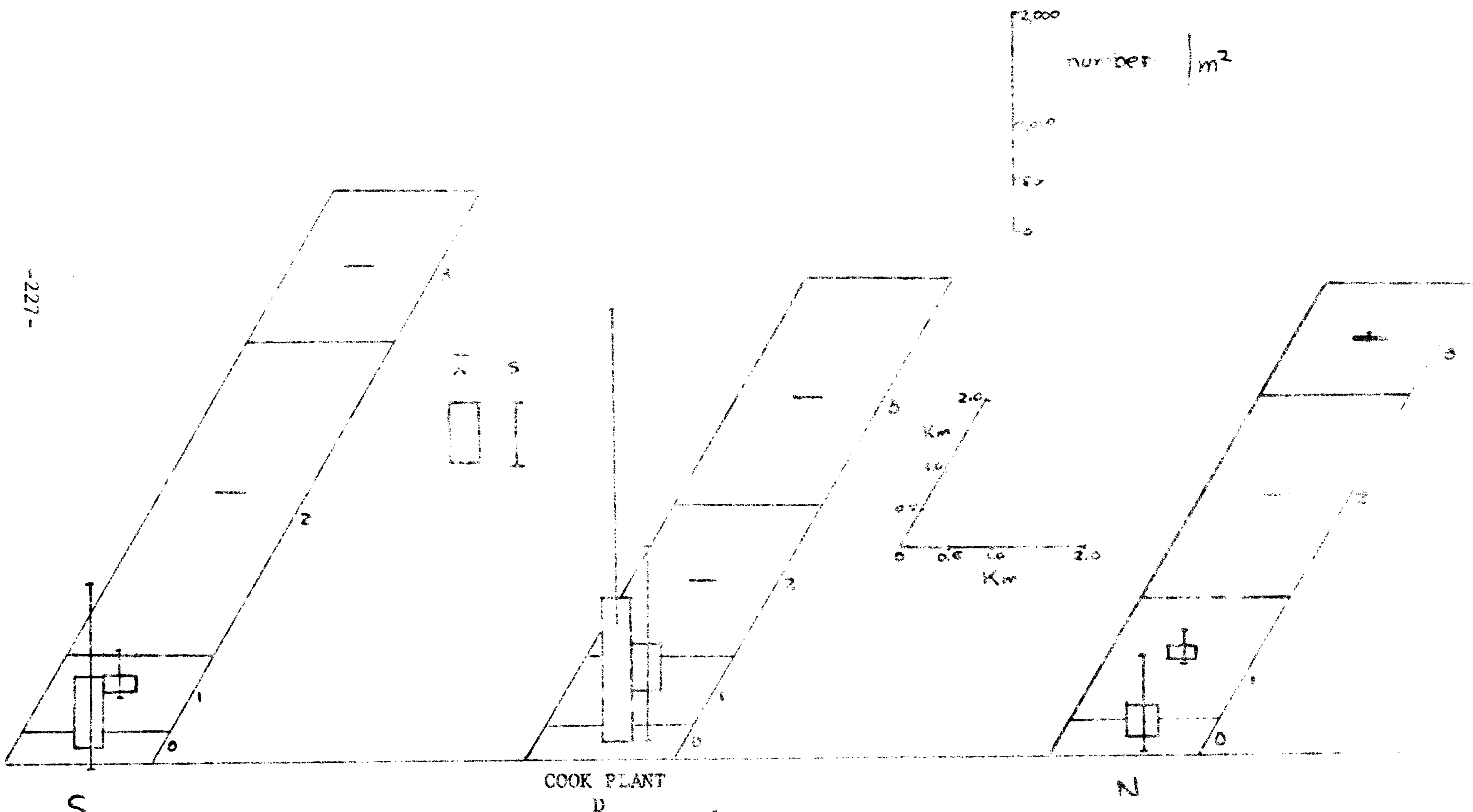


Figure 54. Mean number per m^2 of *Chironomus* anthracinus-group in the 12 zones of the systematic-random survey, July 1972. The inset scale shows numbers per m^2. See Figure 47 for legend.

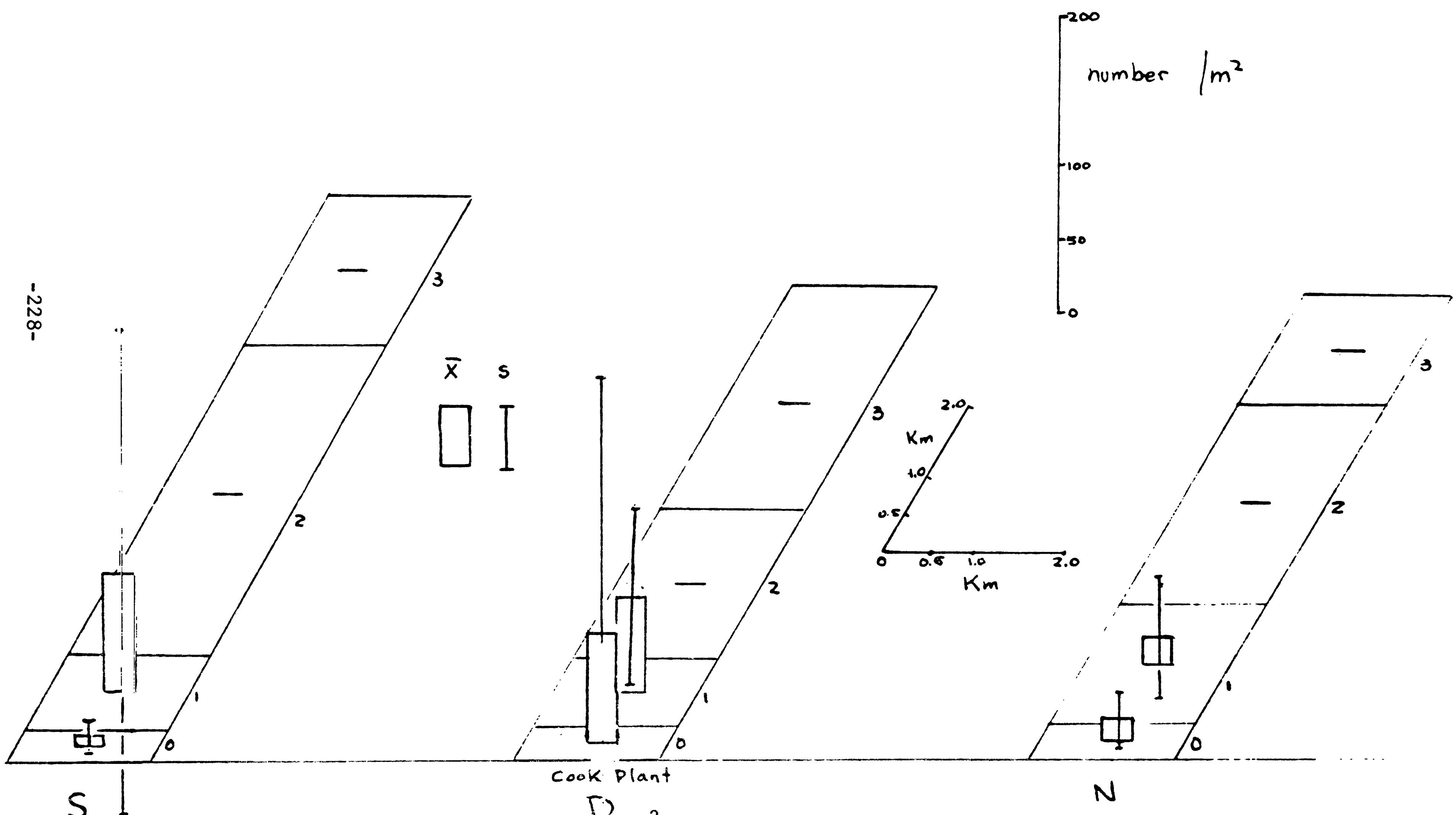


Figure 55. Mean number per m^2 of *Chironomus* fluviatilis-group in the 12 zones of the systematic-random survey, July 1972. The inset scale shows numbers per m^2. See Figure 47 for legend.

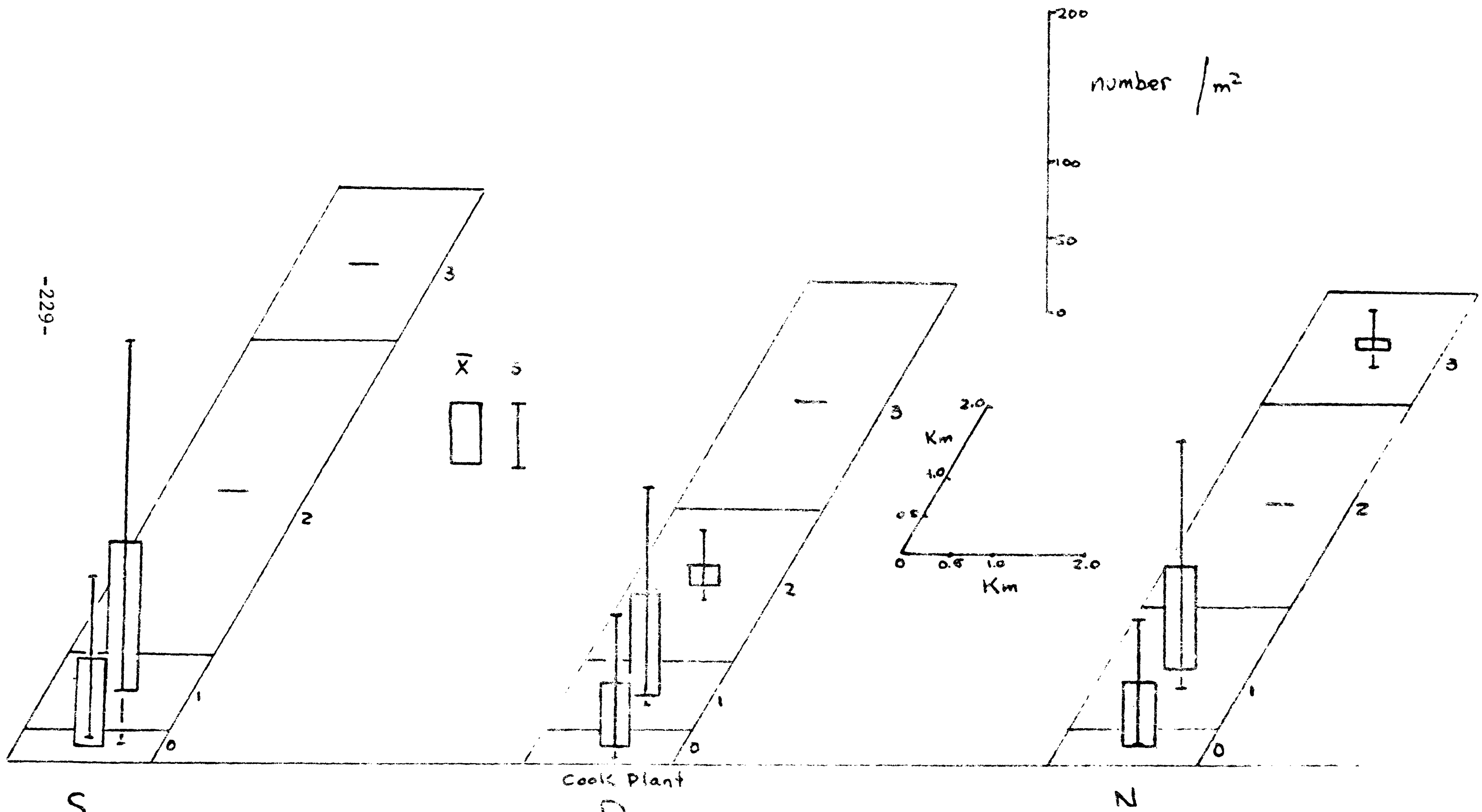


Figure 56. Mean number per m^2 of *Cryptochironomus* sp. 2 in the 12 zones of the systematic-random survey, July 1972. The inset scale shows numbers per m^2. See Figure 47 for legend.

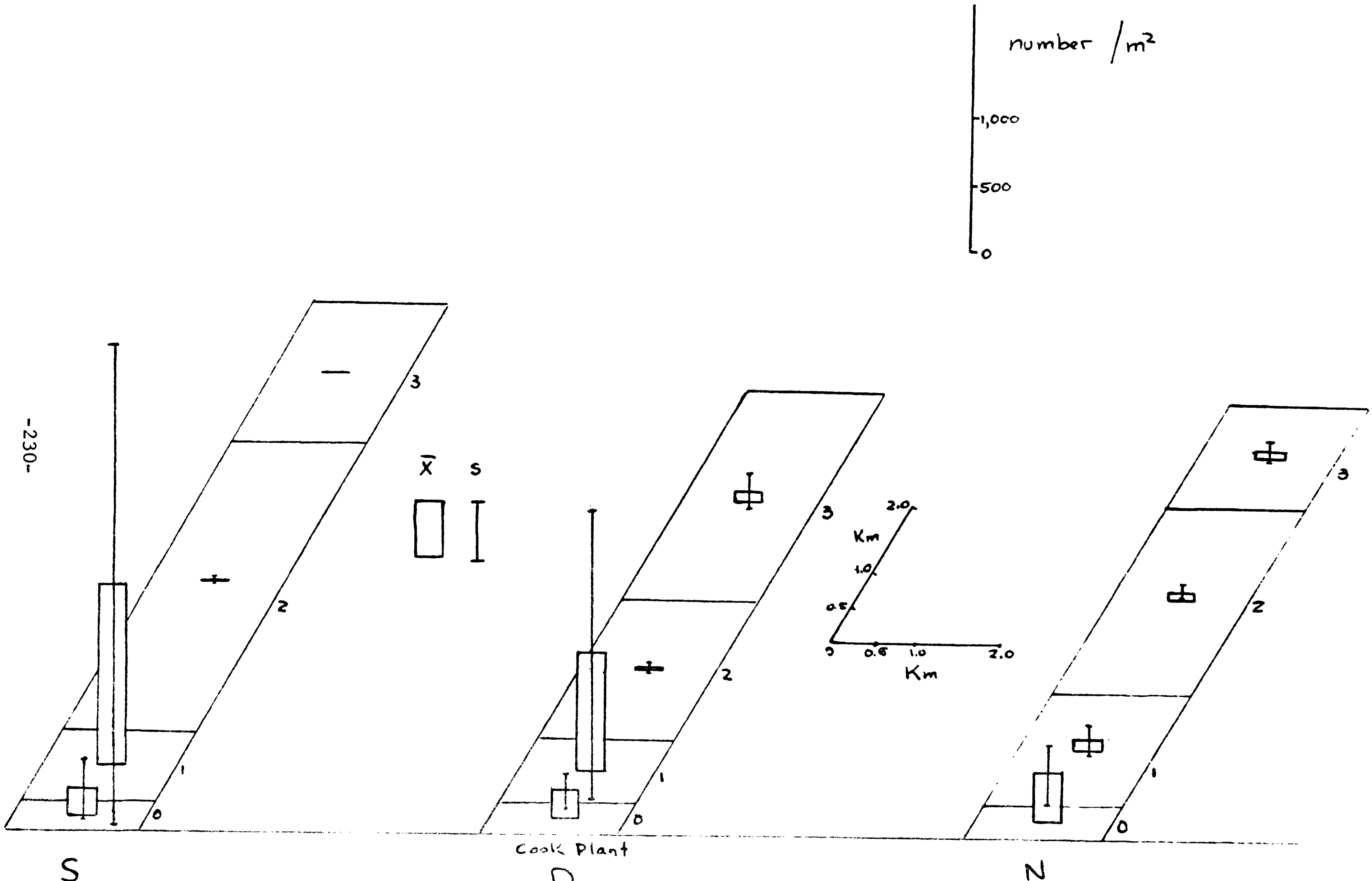


Figure 57. Mean number per m^2 of other Chironomini in the 12 zones of the systematic-random survey, July 1972. The inset scale shows numbers per m^2. See Figure 47 for legend.

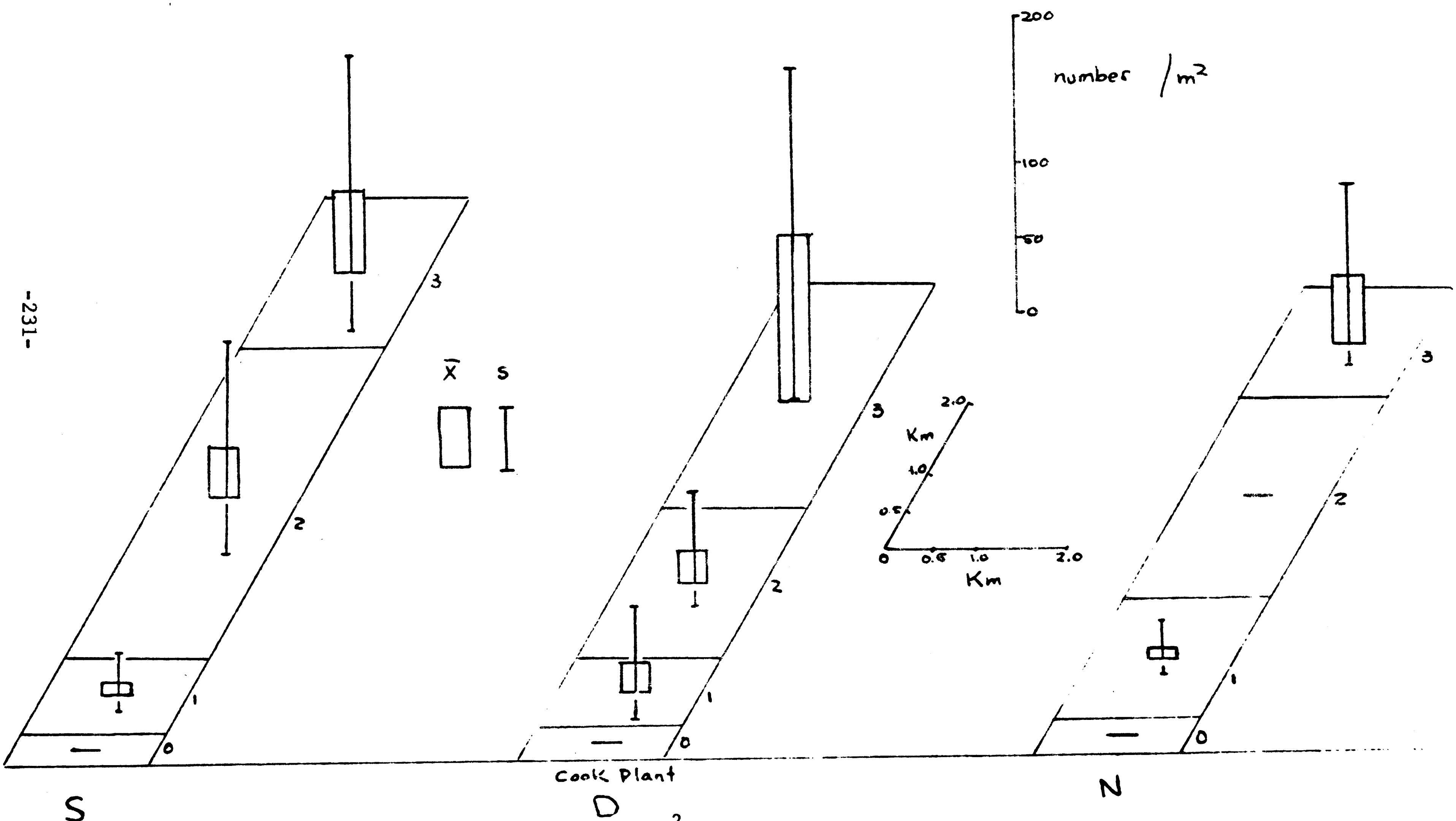


Figure 58. Mean number per m^2 of *Procladius* sp. in the 12 zones of the systematic-random survey, July 1972. The inset scale shows numbers per m^2. See Figure 47 for legend.

Chironomus anthracinus-gr. larvae showed a stronger development in zone 0. The distribution of *C. anthracinus*-gr. in July 1972 was very different from that of July 1970, but not unlike the July 1971 distribution. The small Chironomini which characterize the beach zone (0) were not distinguished below this tribal level, and so were combined with *Polypedilium* cf. *scalaenum*. Since the last is most abundant at depths from 8 to 16 m, this combination of taxa obscured a clear distinction between zones 0 and 1.

In all essentials the patterns of distribution evident from the systematic-random survey plan are the same as those from the former strictly systematic plan. The more recent data, however, illustrate very clearly that the three regions are different; this was not as clear from the earlier plan. The north region is poorer in all taxa. The central region (D) is richer in *Pontoporeia, Sphaeriidae*, and *Chironomus anthracinus*-gr. than the south region, but poorer in Tubificidae, especially in zones 0 - 2. In zones 3, regional differences are somewhat less. Absolute abundances overall were similar to July 1971, but greater than those in July 1970.

Transformation of the data

As a general rule, benthos sample sizes tend to be contagiously dispersed; i.e., most samples have relatively few animals, but a few have very many. A rough test of this general rule is made by comparing the size of mean and variance for replicates. If the variance is much larger than the mean, contagious dispersion is assumed. Comparison of means and variances within zones for the counts per sample (raw data) showed that variances were almost always much higher than the mean. (Note: The squares of the standard deviations in Figures 47 through 58 are not the same as sample variances because data in the figures are converted to numbers per square meter.)

Elliott[3] suggests that when the variances are larger than the means the appropriate transformation is the logarithm of the counts. If there are zero counts a constant of one should be added to all counts before taking the logarithm. Our sample surface areas differed between zones "0" and other zones, so it was necessary to convert the raw data to a common areal basis before performing statistics. Since benthos data are commonly listed in that form, a basis of numbers per square meter was chosen. The transformation formula is:

$$y = \log_{10} (x + 57.4)$$

where x = density in numbers per m^2
y = transformed density

This transformation eliminated the correlation which existed between means and variances. The discussion on "Normal distribution of data" which follows provides evidence that the transformed densities also follow a normal distribution for several important major taxa. To this extent, then, it is a successful transformation.

Normal Distribution of Data

If sets of data are compared by use of the "t"-test, analysis of variance, or other common tests for differences between populations, then all sets should have a normal frequency distribution, i. e., one which approximates a symmetrical, bell-shaped curve. To see such a distribution, one should have at least 50 observations, but the most we had in any single zone was 15. Zones had very different means, so before observations from different zones were combined, the mean was adjusted to 0 by subtracting the zone mean from each observation within a zone. Then all zones were combined to produce a total of 126 observa-

3. Elliott, J. M. 1971. Some methods for the statistical analysis of samples of benthic invertebrates. Freshwat. Biol. Assoc. Sci. Publ. 25. 144 p.

tions. The logarithmically transformed data were used for this treatment. Frequency histograms were plotted with a class interval of 0.1 logarithmic units.

The results for several taxa are presented in Figures 59 through 61. The curves approximate normal distributions sufficiently well for the purposes of our analysis. More detailed tests of the normality of these distributions will be given in a subsequent report.

One-way Analysis of Variance Between Zones

Tables 53 through 55 show the results of analysis of variance using the transformed data. *Pontoporeia affinis* (Table 53) had significantly different population means in all four zones in the north region. The means increased with depth. In the Cook Plant region ("D"), zones 1 and 2 were not significantly different, but all other pairs of zones were different. Again, abundance increased with the depth of the zone. In the south region, zones 2 and 3 were not significantly different, but all other pairs were different. This region also exhibited an increase in *Pontoporeia* abundance with increasing zone depth. The pattern of differences among zones is also illustrated in Figure 48, which further shows that the south region has more *Pontoporeia* in zone 2, but less in zone 3 than the other two zones. The significance of these differences between regions has not been tested, however.

Total Chirnomidae (Table 54) demonstrated a similar pattern in all three regions. The first two zones, 0 and 1, were always significantly different from the deeper zones, 2 and 3. Zone 0 differed from zone 1 only in the north region; otherwise, the two shallower zones were not different, nor were the two deeper zones. As in the case of total animals (next paragraph), however, more differences among zones would be evident if species with differing dis-

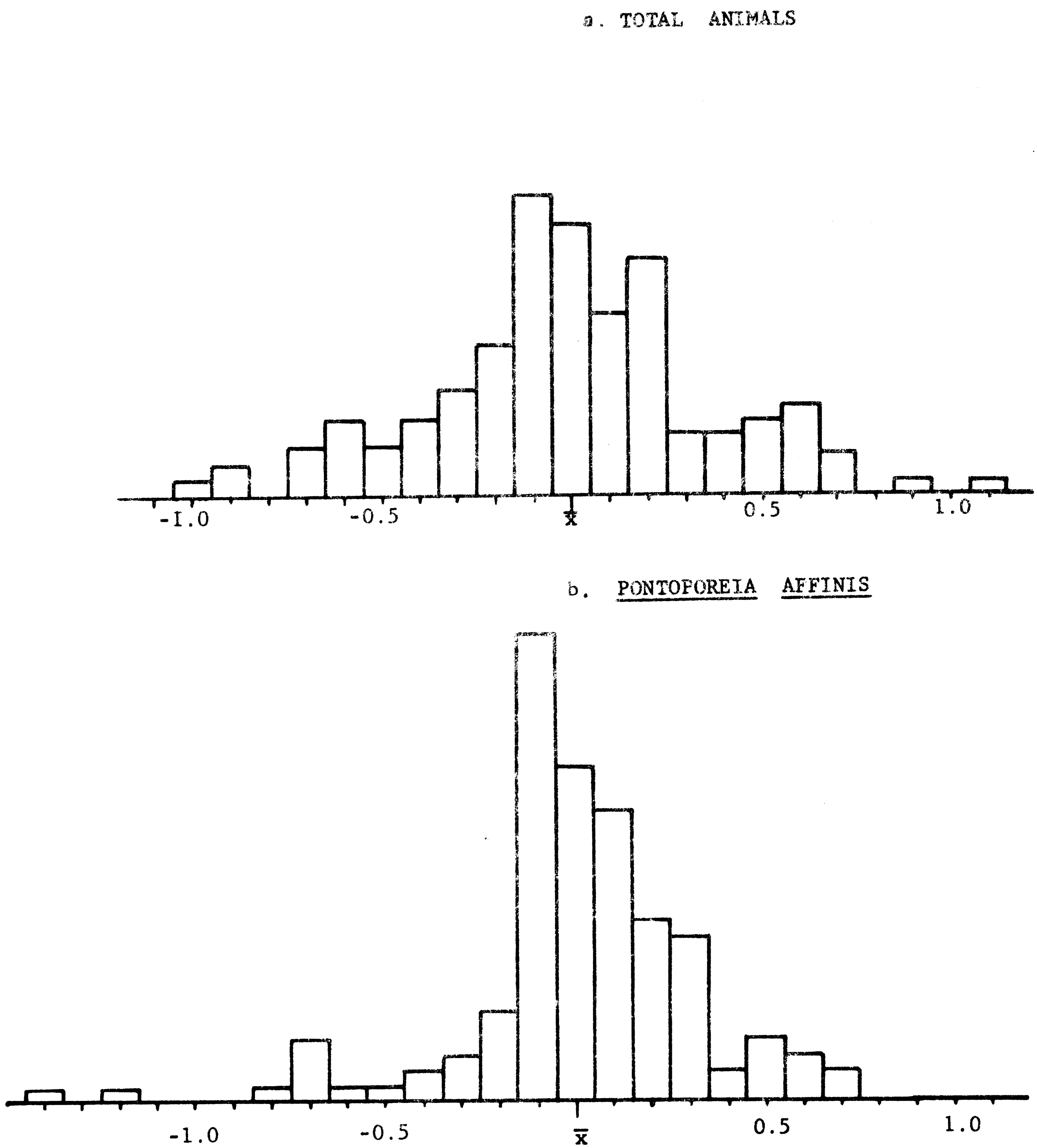
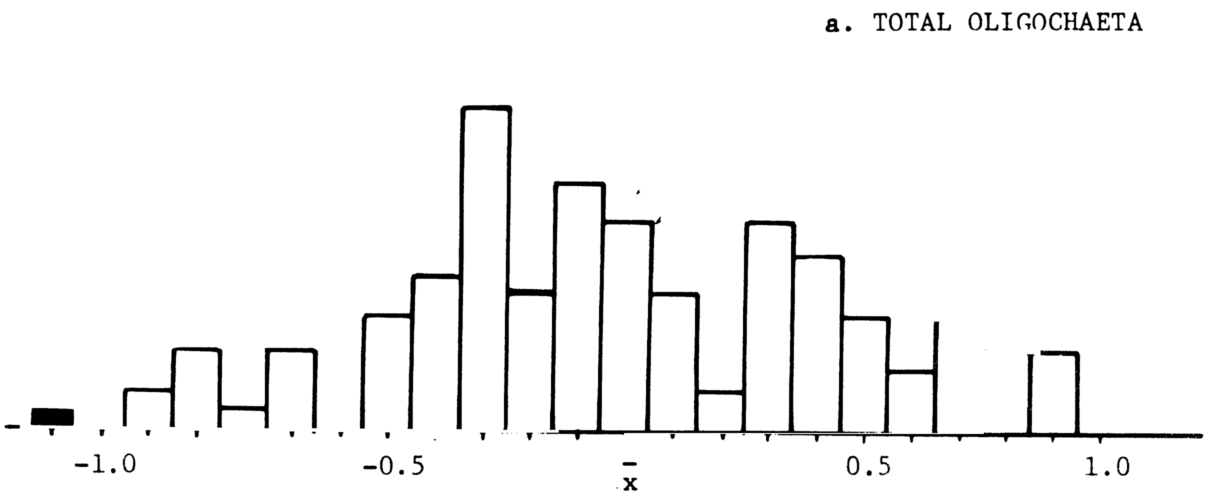


Figure 59. Sample size frequency distributions for total animals (a) and *Pontoporeia affinis* (b) in the systematic-random survey of July 1972. Sample sizes are given as logarithms of the numbers per m^2. Class interval is 0.1 logarithmic unit. The mean class is marked as $\bar{x}$. Vertical axes are numbers of samples within the corresponding size range. All zones and regions were combined by adjusting the means of each zone (see text) to produce 126 observations.



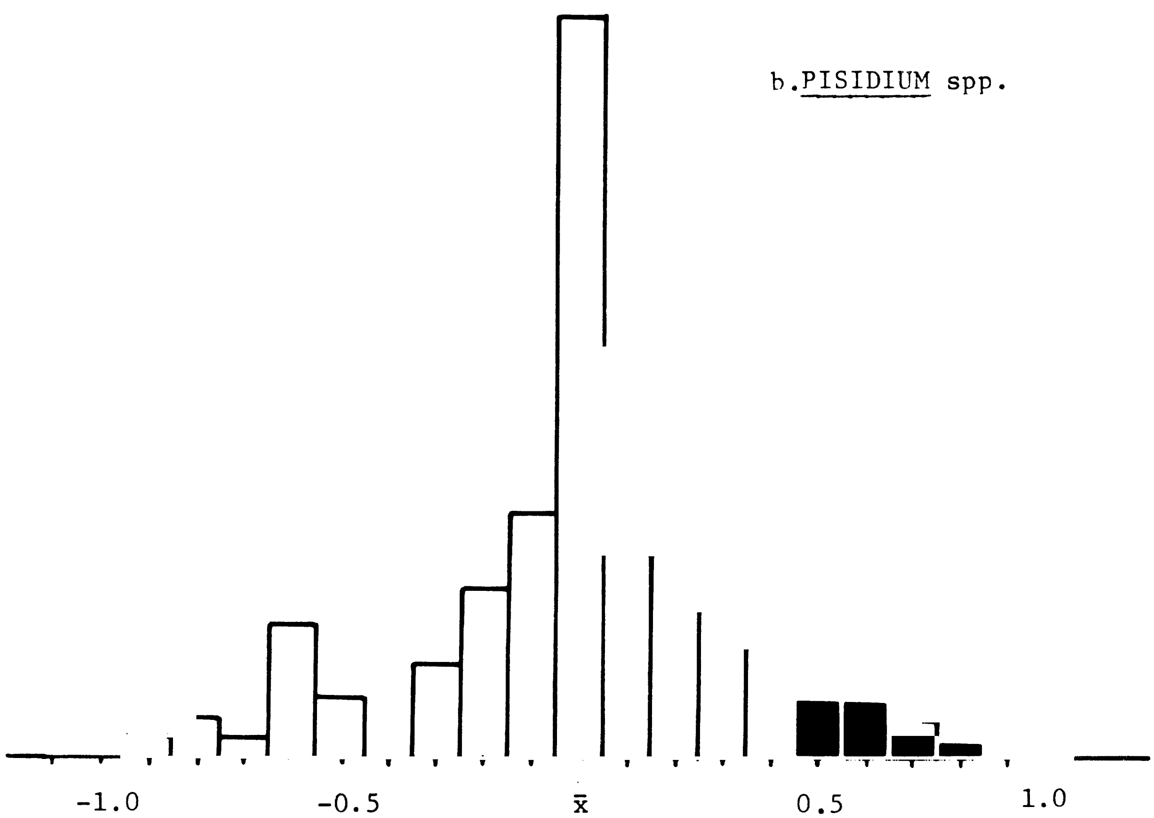


Figure 60. Sample size frequency distributions for total Oligochaeta (a) and *Pisidium* spp. (b) in the benthos survey of July 1972. See Figure 58 for legend.

TOTAL CHIRONOMIDAE

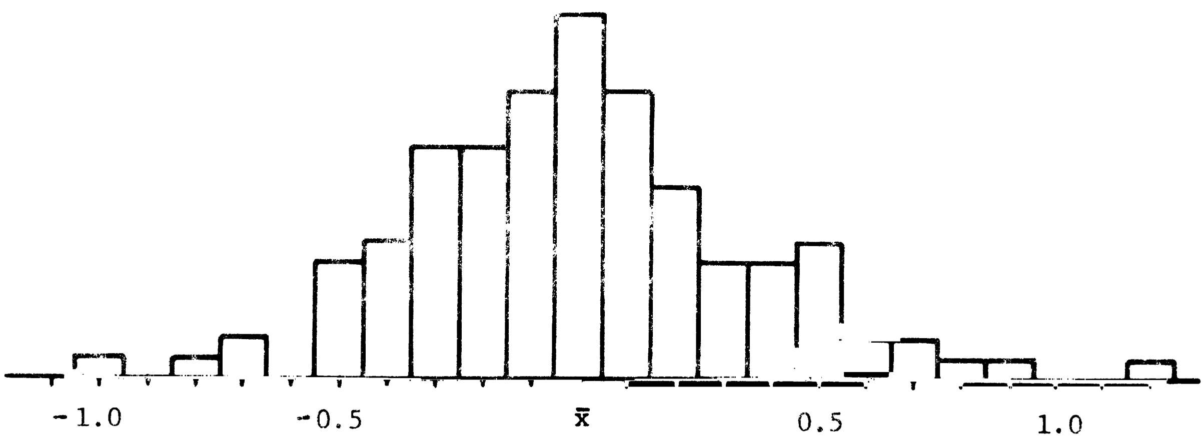


Figure 61. Sample size frequency distribution for total Chironomidae in the benthos survey of July 1972. See Figure 58 for legend.

Table 53. Comparisons of *Pontoporeia affinis* in pairs of zones within each region; July 1972 Cook Plant benthos survey. Letters in the first column refer to the region (N, D, S; see text), while numbers refer to depth zones (0, 1, 2, 3; see text). Means and variances are for the logarithmically transformed data (see text). In each comparison (done as part of ANOVA), the null hypothesis was that the population means of total animals in the two zones were equal. Under "Zone 1" are comparisons between "0" and "1" zones, and under "Zone 2" are comparisons between "0" and "2" zones, and between "1" and "2" zones, etc. If $P \leq .05$, the hypothesis was rejected. If $P > .05$, N.S. (not significant) was entered.

			Comparisons (P)		
Zone	Mean	Variance	Zone 1	Zone 2	Zone 3
N-0	1.87	.03	<.0001	<.0001	<.0001
N-1	2.54	.12		<.0001	<.0001
N-2	3.16	.10			<.0001
N-3	3.78	.08			
D-0	1.80	.01	<.0001	<.0001	<.0001
D-1	2.84	.24		N.S.	<.0001
D-2	3.12	.35			<.001
D-3	3.89	.01			
S-0	1.82	.01	<.001	<.0001	<.0001
S-1	2.49	.38		<.0001	<.0001
S-2	3.44	.23			N.S.
S-3	3.61	.02			

Table 54. Comparisons of total Chironomidae in pairs of zones within each region; July 1972 Cook Plant benthos survey. Format as in Table 53.

			Comparisons (P)		
Zone	Mean	Variance	Zone 1	Zone 2	Zone 3
N-0	2.82	.04	<.05	<.0001	<.0001
N-1	2.54	.11		<.01	<.05
N-2	2.18	.05			N.S.
N-3	2.21	.11			
D-0	2.85	.35	N.S.	<.001	<.01
D-1	2.92	.25		<.001	<.01
D-2	2.04	.06			N.S.
D-3	2.25	.12			
S-0	2.86	.12	N.S.	<.0001	<.0001
S-1	3.09	.14		<.0001	<.0001
S-2	2.10	.04			N.S.
S-3	2.04	.10			

Table 55. Comparisons of total animals in pairs of zones within each region; July 1972 Cook Plant benthos survey. Format as in Table 53.

			Comparisons (P)		
Zone	Mean	Variance	Zone 1	Zone 2	Zone 3
N-0	2.92	.05	<.01	<.01	<.0001
N-1	3.27	.16		N.S.	<.0001
N-2	3.30	.05			<.0001
N-3	4.10	.07			
D-0	2.92	.37	<.01	<.001	<.0001
D-1	3.59	.28		N.S.	<.01
D-2	3.76	.26			<.05
D-3	4.39	.01			
S-0	3.07	.19	<.001	<.0001	<.0001
S-1	3.75	.14		N.S.	<.01
S-2	4.04	.11			N.S.
S-3	4.30	.01			

tributions were not combined into a larger taxonomic entity for analysis. Zones 0 and 1 differ in the composition of Chironomidae species.

Total animals (Table 55) were always significantly different in comparisons between the shallowest and deepest zones. There was no significant difference between zones 1 and 2 in any region, however. In the south region, zones 2 and 3 were not significantly different. Since differences between zones 1 and 2 were significant for *Pontoporeia* and total Chironomidae, we conclude that valuable information is lost when major taxa are combined in quantitative analysis of benthos. In this case, the loss of significance is probably due to the sudden decrease in Chironomidae at a depth of about 16 m, combined with relatively small corresponding increases in the abundances of other taxa.

Summary and Conclusions

A stratified random sampling plan was instituted in July 1972. Strata were established by depth zones in a region in front of the plant and in control regions to the north and south. Benthos were sorted to generic levels or lower. Variances were larger than the means, and generally correlated with them, for all zones, which necessitated transformation of the data prior to statistical analysis. A logarithmic transformation was applied, and was found to produce approximately normal frequency distributions for several taxonomic groupings, as well as eliminating correlations between means and variances. Some of the transformed data were subjected to one-way analysis of variance, and we found that significant differences in population sizes existed between depth zones within regions. This constituted strong support for the intuitive stratification plan, and lent confidence to our ability to detect differences among benthos populations by statistical methods. Ap-

parent differences between the same depth zones in different regions raised the problem of how to compare control and experimental regions when they differ prior to the "experiment." The statistical validity and persistence of apparent differences must be examined, and techniques developed to deal with them, if necessary.

Section 4. *Mysis relicta*

This relatively large (up to 3 cm long) "opposum shrimp" occurs occasionally in benthos samples. It is, however, an atypical benthic animal since during the day it remains near the surface of the sediments while at night it moves up into the plankton. Because of its very sensitive eyes and backward-darting escape reaction, similar to that of the crayfish, it is able to escape capture by bottom grab samples better than endobenthic animals. *Mysis relicta* have been excluded from benthos analyses because data on this species from bottom grab samples are only minimal estimates. Yet its size, its semi-planktonic habits, and its reported sensitivity to thermal shock require that it be considered in the analysis of the environmental impact of the plant.

Data from ponar grab samples are presented in Table 56. These shrimp are more abundant and most frequently captured at the three deepest stations in the survey. Most estimates of abundance were between 8 and 55 per m^2, and the maximum observed was 236 per m^2. Only one specimen occurred in a sample from less than 20 meters in depth. From these data, one would conclude that, at least from April to November, *Mysis* rarely occurs near shore, and is not in serious danger of entrainment. Similar distributions have been observed by several methods in other populations and lakes during the summer period of thermal stratification. Information about this species in the literature, however, indicates that it spreads into the shallows in winter when no thermal barrier exists. Its absence from grab samples collected in shallow water could, then, be a result of its ability to avoid capture, combined with lower population densities there.

On 11 April 1972, an epibenthic sampling sled was used to collect *Mysis relicta* along a transect extending westward from the Cook Plant. The sled was towed parallel to the depth contours for varying time spans, stirring

Table 56. *Mysis relicta* in Ponar grab samples, Cook Plant.

Station	Depth (m)	*Mysis relicta* (No./m^2)							
		Jul 70	Sep 70	Nov 70	Apr 71	Jul 71	Sep 71	Nov 71	Apr 72
NDC-.25-1	13.3	8.4	-	-	-	-	-	-	-
NDC-1-3	21.1	-	8.4	-	-	-	-	-	-
SDC-7-5	22.3	8.4	-	-	-	-	-	-	-
NDC-7-5	24.8	-	16.8	-	-	-	-	-	-
DC-5	25.1	-	25.2	-	-	-	-	-	-
NDC-2-4	26.0	-	-	8.4	-	-	18.2	18.2	-
SDC-4-4	32.2	-	33.6	16.8	36.3	18.2	-	-	18.2
DC-6	39.0	-	16.8	25.2	54.5	-	127.1	36.3	163.4
NDC-4-4	45.0	75.6	8.4	42.0	54.5	54.5	236.1	18.2	54.5

Table 57. *Mysis relicta* in epibenthic sled samples, Cook Plant, April 11, 1972. Water temperature measured with a YSI telethermometer, which had a cable 13.9 m long.

Depth (m)	Temp. (°C)	Tow Time (min.)	*Mysis relicta* (No./min. of tow)
6.2	3.2 (Bottom)	5.0	0.2
6.2	3.2 (Bottom)	5.0	4.0
12.4	3.2 (Bottom)	1.0	109.0
24.8	2.2 (13.9 m)	1.0	255.0
24.8	2.0 (13.9 m)	1.0	39.0
24.8	2.0 (13.9 m)	1.0	127.0
24.8	2.0 (13.9 m)	1.0	120.0
24.8	2.0 (13.9 m)	2.3	246.5

the surficial sediments and entrapping whatever animals occurred in those layers, or just above bottom. A net with 0.6 mm openings trailed behind the sled. Although such collections are at best only rough estimates of population densities (avoidance was still possible at 1 1/2 knots, the speed at which the sled was towed), large numbers of *Mysis* can be collected wherever they are present by extending the length of the tow.

With the sled, *Mysis relicta* was captured at a depth of 6.2 meters, the shallowest sampled just off the Cook Plant. Table 57 presents the results of all tows. Within the limitations of the sled for quantitative sampling, it appears that *Mysis* is rare at the shallower depths.

In conclusion, it is clear that *Mysis relicta* does occur at depths which are shallow enough to expose it to entrainment and heated effluent, at least in April. The bottom-sampling grab is not capable of detecting its presence, either because the shrimp is so rare, or because of its avoidance abilities. Quantitative estimates of its abundance are very difficult to obtain. Since it becomes planktonic at night, perhaps the best method of estimating its abundance is to collect it from the lakewater intake system during nocturnal hours. Its absence from the intake samples of January 1973 (see Section 5) implies that it is not entrained in large numbers, at least in the daytime.

Section 5. Benthos in Cook Plant cooling water, January 1973

Samples from the intake bay of the cooling water system were sampled qualitatively with a #15 plankton net. These samples contained sand and benthic organisms in addition to plankton. The occurrence of benthos indicates that some of the benthos are semiplanktonic and that others are maintained in suspension sufficiently far above bottom to be taken into the cooling water duct. Moreover, certain species in the cooling water may have originated from the riprap around the intakes, rather than from the open sandy bottom.

Results

Intake Bay Sample (plankton net)

Amphipoda

Pontoporeia affinis - 7. Six were mature males, and one a mature female. The female and two males had begun to decompose before collection. Five males could be positively identified as of the subspecies "brevicornis," and the sixth could not be determined, due to absence of antennae. Prior to this sample, only one mature male had ever been seen in Cook Plant samples.

Oligochaeta

Tubificidae

Limnodrilus hoffmeisteri - 3. This is a common species throughout the survey area.

Peloscolex freyi - 1. This is a frequent species in benthos samples between 8 and 20 meters.

Immature Tubificidae without hair setae - 22.

Ilyodrilus templetoni - 2. This is the first record of the species from the survey area. It has no definite indicative significance, but is associated with polluted shorelines in the Great Lakes.

Immature Tubificidae with hair setae - 2.

Insecta

Diptera

Chironomidae

Chironomus fluviatilis group - 14 in instar III. 11 had died before being sampled. This larva is common from 4 to 13 m.

Cryptochironomus "sp. 2 type" - 3 in instar IV. Frequent from 4 to 13 m.

Polypedilum scalaenum - 2 in instar II. Frequent from 8 to 16 m in summer.

Paracladopelma nereis - 1 in instar III. Common from the beach to 6 to 8 m.

Procladius sp. - 3 in instar III or IV. Abundant from 13 to 25 m in summer.

Other Fauna

Hirudinea - 1. Not *Helobdella stagnalis*. May be a new record for the Cook Plant. Even if not it may be considered a rare form in the benthos.

Hydra sp. - 9. Frequent in benthos samples.

Trichoptera sp. - 3. At least 2 instars represented. This order of insects is extremely rare in the survey area.

DP Samples

The DP samples described below were collected by passing water, pumped from the intake forebay by a diaphragm pump, through a #10 plankton net suspended in a water filled barrel.

DP-3

Oligochaeta

Lumbruculiidae

Sylodrilus heringianus - 1. Usually found deeper than 12 m.

Tubificidae

Immature Tubificidae without hair setae - 6.

Chironomidae

Chironomus fluviatilis group - 6 in instar III. Four died before being sampled.

Paracladopelma nereis - 3 in instar III.

Procladius sp. - 2.

Monodiamesa bathyphila - 1 in instar IV.

Other Fauna

Hirudinea - 2. Not *H. stagnalis*

DP-2

Amphipoda

Pontoporeia affinis - 5. All male subspecies *brevicornis*. One had died before being sampled.

Oligochaeta

Tubificidae

Limnodrilus profundicola - 1.

Immature Tubificidae without hair setae - 11.

Immature Tubificidae with hair setae - 6.

Naididae

Piguetella michiganensis - 1.

Chironomidae

Chironomus fluviatilis group - 2 in instar III.

Procladius - 3 in instar III. One died before being sampled.

Other Fauna

Hirudinea - 1. Not *H. stagnalis*.

Hydra sp. - 2.

Inferences

The absence of *Pisidium* indicates that some winnowing does occur, and that only lighter species will be taken into the cooling water. *Pisidium* generally occurs along with Oligochaeta.

Several forms, due to their disproportionately high frequency, appear to be more liable to occur in the water above bottom than other benthos: *Pontoporeia affinis* males and *Procladius* and *Chironomus* fluviatilis-group larvae. The last of these three forms is the only surprising one, in that *Chironomus* larvae generally occur in the plankton only at night and just before pupation (late instar IV).

Several forms indicate the contribution of stable, hard bottoms to these suspended benthos: *Hydra*, Trichoptera and Hirudinea.

The frequency of *P. affinis* mature males shows that this must have been near the main reproductive period for the species, for mature males are very short-lived.

The fewer numbers of benthos in the "DP" (pumped) samples probably reflect a smaller volume of water sampled. No difference in depth of sampling

existed among the three samples. It is not possible from available data to calculate the density of benthos in the cooling water.

The frequency of individuals which had died prior to collection reflects either the harsh conditions existing in the intake ducts or the greater tendency of dead animals to be suspended in the alongshore currents. The rate of non-predatory mortality of benthos in the shore zone is unknown.

The presence of several elements of deeper-water benthos associations suggests that winter migrations or transport by upwellings or onshore currents were occurring during the sample period. These elements are *Monodiamesa*, *Procladius*, and *Stylodrilus*.

A.8 *Study of Local Fishes*

This segment of the annual report has been published under separate cover as Part XII of this report series:

Studies of the fish population near the Donald C. Cook Nuclear Power Plant, 1972. March 1973. D. J. Jude, T. W. Bottrell, J. A. Dorr III, and T. J. Miller. 115 p.

A.9 *Support of Aerial Scanning*

Under our contract with Indiana & Michigan Power Company, we are obligated to "ground truth" in the surface water of Lake Michigan whenever the company decides that overflights carrying remote sensing systems are desirable. We are ready to provide this service on demand accompanied by adequate lead time.

A.10 *Study of Entrainment and Impingement*

This is an addition to the annual report. The study of the effect of entrainment and impingement is in the preliminary stages. Samples have been taken and are being analyzed to determine the validity of the techniques we anticipate using for this portion of the study. A very short description of what is planned is provided here but these comments should be regarded as preliminary and changes should be anticipated as the progress of this work continues.

Preliminary investigations of the effects of entrainment of living organisms in the open circulating cooling system were initiated in January 1973. The investigations are directed towards the following biological groups: benthos, fishes, phytoplankton and zooplankton. Attempts will be made to ascertain whether mechanical damage occurs and to what extent it occurs. Determination of possible mechanical damage during cold water circulation in the cooling system should provide the opportunity to see what the resultant thermal effects may be once the Donald C. Cook Plant goes on line.

The entrainment studies on fish include adult, juvenile, larvae and eggs. The existing traveling screens can be expected to cause almost 100% mortality of all fish large enough to be entrained on the 3/8" mesh of the screens. A comparable mesh to that on the traveling screens has been installed in trash baskets which filter the wash water from the traveling screen. Initially all fish caught in this basket will be examined but eventually subsampling of the collected fish may be necessary. Fish larvae and egg collections are to be made by filtering water provided by diaphragm pumps pumping from the intake bay in front of the traveling screens through # 5 plankton nets.

The zooplankton studies on entrainment have progressed further than oth-

er portions of this work to date. Additional information on zooplankton entrainment is found in this report in A.5. The general procedure of the zooplankton study is summarized below. Samples are collected by diaphragm pumps and a #10 plankton net. Work is being done to determine the horizontal and vertical distribution of zooplankton in the intake forebay. Distributional information thus derived will be used to determine sampling depths and locations for fish larvae and phytoplankton. Techniques to measure viability of zooplankton before and after entrainment are being tested.

Phytoplankton samples are collected by volumetric sampling of intake forebay water from the discharge of the diaphragm pumps. Viability of phytolankton before and after entrainment will be determined by C_{14} productivity comparisons.

Preliminary benthos samples have been taken and are reported in A.7 section 5 of this report.

Sampling frequency investigations are planned once the open circulating water system commences to operate. Sampling frequencies will depend on the results of these investigations and on external requirements.

B. SURVEYS OF EXISTING WARM WATER PLUMES

During the past years we have spent a good deal of time and energy in conducting surveys of existing warm water discharge plumes from existing power generating stations. If desired, this program could be continued; we believe, however, that since we have already surveyed the plumes of all the major power stations on Lake Michigan, the emphasis and manpower should be transferred to the rising numbers of biological problems directly related to the Cook Plant and its environs. To that end, this section on surveys of existing warm water plumes is considered FINISHED.

C. THE ICE BARRIER AT THE COOK PLANT SITE

As in previous winters, studies of the ice barrier at the Cook Plant and in other areas were conducted by foot surveys and by aerial overflights. During the winter of 1972-1973 they were supplemented by fixed-position time lapse photographs.

Foot surveys of shore ice conditions at the Cook Plant were carried out on 20 December and 27 December 1972, and on 3 January, 6 January, 12 January, 19 January, 31 January, 15 February, and 22 February 1973. Aerial surveys of ice conditions along the southeastern shore of Lake Michigan were conducted on 27 February and 9 March 1973. The automatic time lapse monitoring camera was put into operation at the Cook Plant on 27 December 1972. The camera repeatedly photographed the same area of shoreline and nearshore water immediately to the north of the plant. With one breakdown, the camera operated

continuously from 27 December until breakup in March. During the camera breakdown, comparable pictures were taken by plant personnel, to whom our thanks are tendered.

D. EFFECTS OF EXISTING THERMAL DISCHARGES ON LOCAL ICE BARRIERS

Foot surveys of the plume areas of the Palisades and Campbell plants were made on 11 January. Our overflight of 27 February covered the plumes of the Bailly and Michigan City plants of NIPSCO and the Palisades and Campbell plants of Consumers Power. The overflight of 9 March covered the plume areas of Bailly and Michigan City.

A report of our 1972-1973 winter operations will be prepared when processing and analysis of photographs and field notes can be completed.

E. EFFECTS OF RADIOACTIVE WASTES IN THE AQUATIC ENVIRONMENT

E.1 *Gamma Scan of Bottom Sediments*

This section, which we early recognized as a desirable part of the Cook Plant preoperational survey program, has been taken over and in large part completed by Dr. Philip Plato of the University of Michigan School of Public Health. In view of his successful efforts, and in view of rising demands upon us for biological studies directly related to the Cook Plant and its environs, we consider that, so far as the Great Lakes Research Division program is concerned, this section of the work plan is FINISHED.

E.2 *Benthic animals as monitors for the accumulation of radioisotopic wastes in the biota of coastal Lake Michigan.*

S. C. Mozley

Introduction

An experiment was designed to measure the relative reconcentration of certain metallic radionuclides by animals under conditions which approximated the natural environment. A variety of benthic macroinvertebrates was exposed to five radionuclides so that the most sensitive monitoring animal for each could be distinguished.

Criteria for selection of the monitoring animal or animals should include:

1) ability to accumulate a radionuclide from the aqueous phase against a concentration gradient of several orders of magnitude;

2) continuous abundance at the depth of the outfall in southeastern Lake Michigan; and,

3) simplicity of collection and ease of concentration from the sediments in large quantities.

Benthic macroinvertebrates were selected for this study because their populations are more stable in time and space than zooplankton and phytoplankton, and they move about much less than fish. No macrophytes have yet been found growing in the survey area. The only unexamined potential groups of monitoring organisms are the algae and animals which develop on hard substrata such as stones and wood.

A variety of radionuclides are released into the coolant water of nuclear electrical generating stations. Most of these are present in very minute quantities and probably represent no direct hazard to the benthos or benthophagic animals. Some however, are important to living cells and are accumulated from

the environment against a concentration gradient. Since only a few radionuclides can be studies efficiently at one time, those of known or suspected biological importance, which disappear only slowly from the environment by radioactive decay, and which are easy to distinguish quantitatively in mixtures were chosen for these experiments.

The Palisades Nuclear Power Plant of Consumer Power Company, a new plant of similar design to the Donald C. Cook Nuclear Power Plant, has been releasing radionuclides into Lake Michigan for about a year. The major components of its radioactive wastes and its release of the elements studied here are listed in Table 58. Isotopes of Hydrogen (H-3), Cobalt (Co), Chromium (Cr), Xenon (Xe) and Iodine (I) were most abundant. Millicurie amounts of Cesium (Cs), Manganese (Mn) and Zinc (Zn) were also released, but only insignificant quantities of Barium (Ba) and Cerium (Ce) appeared in the effluent. Chromium and Iodine have relatively short-lived isotopes, and tritium is generally assumed to be diluted rapidly by natural hydrogen in the water. Cobalt would have been a good object for study, but our supplies were exhausted in preliminary experiments. Sodium (Na) was released only initially from Palisades and amounts in the last three quarters of 1972 were negligible.

None of the beta-emitting isotopes were studied because of the necessity for more involved procedures and completely separate counting apparatus. The five radionuclides which were included in the present study are strong alpha-emitters with distinct peak energies, and they can be counted simultaneously on a low resolution NaI crystal detector.

Methods and Materials

The experiment was conducted in triplicate in 3.85 1, wide-mouthed glass jars with lake water which had been filtered during collection through a #28

Table 58*. Palisades Nuclear Power Plant; 1972 liquid radioactive effluents.

Radioisotope**	Millicuries 1st Qtr	2nd Qtr	3rd Qtr	4th Qtr
Ce-144	0.0	0.058	0.005	0.0
Ba-133	0.0	0.0	0.0	0.0
Cs-137	0.017	1.52	11.8	0.99
Mn-54	4.2	2.8	31.1	53.8
Zn-65	0.0	0.004	0.06	3.8
Other Major Isotopes				
Cr-51	2.027	39.3	220.4	2,512.7
Co-57 + 58 + 60	70.27	85.53	329.3	2,745.3
Na-24	15.8	0.022	0.10	0.0
I-131 + 133	69.1	42.73	97.6	37.03
Xe-135 + 133	64.0	277.7	881.9	651.7
(H-3 excluded, very abundant)				
Fe-59	0.26	0.94	12.0	53.8
Zr-95	0.32	0.92	2.2	28.1
Nb-95	0.07	1.8	2.3	33.8
Sb-124	0.0	0.81	0.35	8.1

*From Consumers Power Company Palisades Plant. Semiannual operations report. No. 4. July 1-December 31, 1972.

**For 1972 most abundant radionuclides were Cr-51 (2.8 Curies), Co-58 (3.2 Curies), H-3 (120 Curies), Xe-133 (1.8 Curies), and I-131 (0.2 Curies). 0.3 Curies of unidentified radioactive material was also released.

phytoplankton net. Sand with a grain-size range between 0.125 and 0.500 mm, and washed thoroughly in lake water, was added to each jar to the amount of 250 ml (settled wet volume). The jars were held in incubators in the dark with continuous aeration by bubblers. Incubator temperatures during the experiment varied between 11.0 and 15.7° C.

Figure 62 shows the progression of a temperature rise which occurred during the experiment. The incubators were being maintained at a positive difference above outdoor temperatures. When unusually warm weather occurred during the experiment the incubator coolers malfunctioned and the internal temperatures rose. This rise may have caused part of the mortality of *Sphaerium nitidum* and *Pontoporeia affinis* during the experiment, as they prefer cooler habitats. It may also have interfered with normal uptake by other animals. Nevertheless, the change is well within the range of temperatures for a single summer day at the depth of the outfall (about 6 meters).

The radionuclides were provided by the suppliers as dissolved, inorganic ions in HCl. When they were added to lake water, the pH of the total was less than 1. Before the radioactive lake water could be added to the experimental jars, it was necessary to neutralize it. This required 350 milliequivalents of NaOH, and produced a salinity of 0.17 g/l (= 0/00) above the normal lake water. The effect of this slight increase in salinity on the experimental animals was not lethal, but may have reduced their tendency to accumulate inorganic ions from the water somewhat. Neutralization of the radioactive lake water occurred four hours before it was added to the jars, which may have allowed some of the radionuclides to form colloidal-sized or larger particles before they came in contact with the animals.

Eleven kinds of benthic animals were included in the experiments (see Table 59). Some of these kinds included several species which cannot be dis-

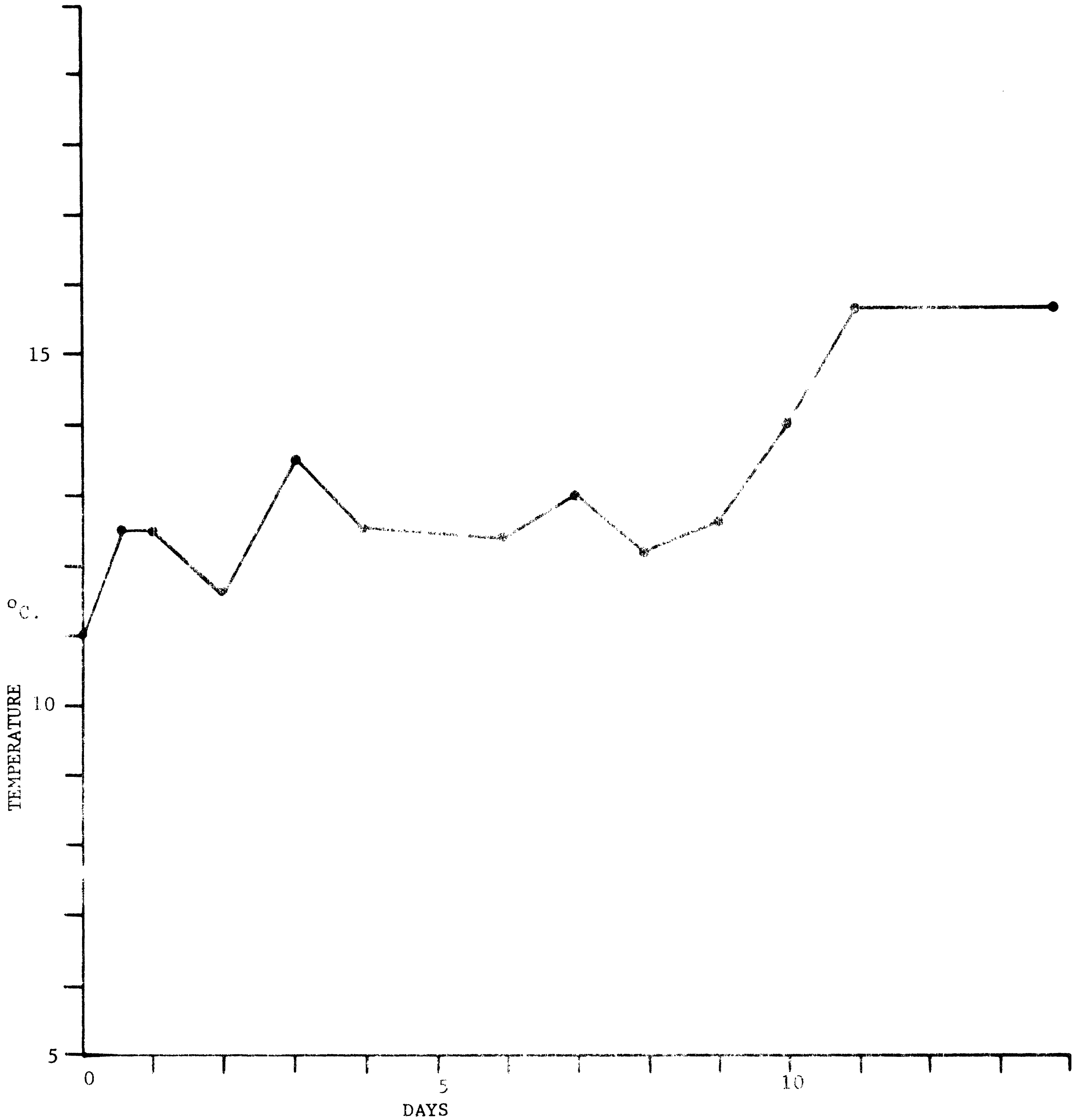


Figure 62. Variation in incubator temperature during the experiment. Temperatures were measured when water samples were taken.

Table 59. Survival of animals during the experiment. (Conversion factor to #/m^2, for jar with diameter 15 cm: 56.5)

Taxon	# at t=0	# Counted	# Shells Recovered
Lymnaea spp.	17(x3)	17, 17, 15	0, 0, 2
Valvata spp.	11, 11, 12	11, 10, 12	0, 1, 0
Sphaerium nitidum	23(x3)	16, 14, 18	5, 7, 5
S. striatinum	1 (in A)	1 (from A)	0
Pisidium spp.	28(x3)	23, 32, 34	6, 4, 6
Oligochaeta	50(x3)	34, 39, 49	1 or more lost in sieving
Helobdella stagnalis	3(x3)	1, 3, 3	
Chironomus anthracinus-gr.	1(x3)	1(x3)	
Tanytarsini sp.	50(x3)	30, 8, 9	18 or more lost in sieving
Procladius spp.	2, 3, 3	2, 3, 3	
Pontoporeia affinis	12, 11, 11	6, 7, 6	
Mysis relicta	1, 1, 0	0	no trace remained

tinguished at the macroscopic level. Oligochaeta included *Stylodrilus heringianus* and several species of Tubificidae. *Lymnaea, Valvata, Chironomus anthracinus*-group, and *Procladius* may have included two or more species each. *Pisidium* included several species. The species *Pontoporeia affinis* was represented by a wide size range of specimens, including some as small as 3 mm long and one gravid female.

To compare the final radioactivity of sand and water with animals, all counts were adjusted to similar units of weight or volume. The common basis for animals was one gram, formalin wet weight. The weights of the animals of each kind in each jar were determined at the end of the experiment on a Mettler balance to the nearest 0.1 mg. The radioactivity of a set of animals was then divided by its wet weight expressed in grams.

The numbers of each kind of animal introduced into the jars at the start, and the numbers recovered and measured at the end, are given in Table 59. The densities of animals in the jars at the start were within ranges of densities found in the lake. Prior to the experiment, the animals had been held for four months at 10 $\pm 3^{\circ}$ C in the dark in natural lake water and sediments.

The experiment lasted 14 days. When the radioactive lake water had been thoroughly mixed in the jars, 3 ml samples of water were drawn from the surface at time 0, time 14.5 hours, and 24 hours, then at one-day intervals thereafter. At time 14 days, the water and sand were poured through a 0.6 mm sieve and the entrapped animals were sorted by kind to be measured. The sieved sand was rinsed once in non-radioactive lake water and a 3 ml sample of sand was transferred to a counting dish. Interstitial water and radionuclides weakly adsorbed on sand, jars or animals were not measured.

Since sorting the animals took 2 - 3 hours for each container, and since they were all held at least one hour in non-radioactive lake water, they had

some chance to egest radioactive materials in their guts and exchange radionuclides with the water physiologically. This period was not long enough for complete egestion of materials in the gut or attainment of physiological equilibrium. It does represent however, the sort of delay which will be likely between collection and transferral to counting dishes of monitoring organisms in the field.

Animals, sand, and water were counted in 5 ml plastic petri dishes on a "2 x 2" NaI-Th detector connected to an ND-555, 128-channel analyzer. Counts in each channel were printed by a teletypewriter. Five channels around one peak for each radionuclide were summed, backgrounds were subtracted, counts in the peak region due to other radionuclides were subtracted by the method of simultaneous equations (derived from individual standard spectra with the same geometry and counting apparatus), and counts were corrected for radioactive decay to 19 February 1973 (day 0). Concentration ratios were calculated for sand and each kind of animal in each replicate by dividing counts per gram of animals or per milliliter of sand by the counts per milliliter in the water at the end of the experiment. Since the animals were mostly in more direct contact with the sand than the water, counts per gram for each animal were divided by the counts per milliliter for sand. Some sets of animals covered the bottom of the dish (e. g., *Lymnaea, Sphaerium nitidum*), while others were small enough to fit into a 0.5 ml drop or less. Accordingly, separate standards of radionuclides were counted with both 3 ml and 0.5 ml volumes for determination of the coefficients for the simultaneous equations. The analyzer was calibrated to linearity at 10 kev/channel at least once every four hours during measurements, and a fresh background spectrum was determined after each calibration. Background and samples of low radioactivity were counted for 1,000 seconds, but more radioactive samples were counted only long enough to

obtain clear definition of all the peaks on an oscilloscope screen, sometimes as briefly as 350 seconds. No attempt was made to determine absolute activities, since relative measures were sufficient.

Results

The counts determined by the method of simultaneous equations in the peak region of each radionuclide are given by sample, unadjusted for decay, in Table 60. Although the actual counting interval was 1,000 seconds (see methods section), the counts are reduced for compact presentation to the equivalent counts for 10 seconds. Count totals less than 1 per 10 seconds (100 per 1,000 seconds, or 20 per channel per 1,000 seconds) were statistically unreliable. The limit of detectability in the procedure was about 10 - 20 total counts per 1,000 seconds. *Sphaerium striatinum* was present in only one replicate. The bottom three rows of entries in the table are the sizes of the samples which were actually counted, in milliliters for sand and water, and in milligrams for animals. The weights of animals are those actually retrieved from the jars and counted.

Table 59 shows the relation between the numbers put into each jar and the number retrieved and counted for each kind of animal. Losses during the experiment were heaviest for *Sphaerium nitidum* (most shells recovered), *Pontoporeia*, Oligochaeta and Tanytarsini sp. The last two kinds of animals may have suffered some aquarium mortality, but the greatest loss (as always) occurred during sieving -- some specimens were unavoidably discarded with the waste sand. Numbers of *Pisidium* increased during the experiment, presumably from the releasing of young clams (they are viviparus) which were already developing before the experiment began. A few *Pontoporeia* may have escaped through the sieve, as well, but this species generally suffers heavy mortality in culture,

Table 60. Measured radioactivity (counts/10 seconds), uncorrected for decay, of samples of water, sand, and animals at the end of the 14-day-long experiment, as well as the quantity of material in each sample. The initial (measured) radioactivity of the water (t=0) is also given. A, B, and C were experimental replicates.

	Ce-144			Ba-133			Cs-137			Mn-54			Zn-65			Vol or Wt[1]		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Water (t=0)	189	624	519	438	472	454	558	592	583	23	73	61	6	21	17	3	3	3
Water (t=14 days)	5	6	6	117	111	109	33	34	30	<1	<1	<1	<1	<1	<1	3	3	3
Sand[2]	1,498	9,300	3,659	4,341	5,447	4,164	5,768	8,853	5,230	166	1,024	416	49	250	120	3	3	3
Lymnaea spp.	888	1,537	1,322	1,871	1,676	1,316	1,517	1,329	976	160	484	270	74	185	111	920	888	819
Valvata spp.	228	460	572	357	262	428	264	198	312	56	141	151	50	118	160	142	125	167
Sph. nitidum	264	406	489	631	355	692	455	402	385	39	88	97	24	60	56	655	574	703
Sph. striatinum	15			10			28			2			3			40		
Pisidium spp.	100	255	268	661	1,059	1,112	113	121	135	13	52	55	10	40	38	66	90	87
Empty shells spp.[3]	134	232	527	677	465	1,390	41	49	179	24	61	128	13	18	50	73	106	138
Oligochaeta spp.	171	378	332	252	237	276	298	267	258	17	44	37	7	19	19	147	185	224
Hel. stagnalis	2	5	2	2	1	2	3	4	3	<1	2	1	1	3	1	20	33	23
Ch. anthracinus-gr.	4	37	33	2	6	4	3	15	11	<1	4	3	<1	<1	<1	7	11	11
Tanytarsini sp.	315	208	261	74	18	19	220	49	58	28	18	20	4	3	3	28	7	7
Procladius spp.	1	3	5	1	1	1	2	1	2	<1	<1	1	~0	<1	<1	4	7	7
Pont. affinis	7	54	37	40	52	36	9	19	18	1	0	6	<1	1	<1	10	15	5

[1] Volume expressed in ml for water and sand; weight expressed in mg for animals.

[2] Sand volume was measured from wet, settled sand. Counts are sum of 5 channels around one peak for each isotope. Corrections for interference by other isotopes in the peak region were made with the method of simultaneous equations.

[3] Empty shells were from Sphaeriidae and Gastropoda which died and whose flesh was removed by decay or scavengers during the experiment.

especially when the temperature rises as high as it did in this experiment.

The five radionuclides decreased rapidly in the water during the experiment. Manganese -54 (Figure 63) underwent nearly constant exponential decline to the limits of detectability by day 5.

Zinc -65 (Figure 64) decreased steeply in the first 15 hours, then declined nearly exponentially from then until day 6, when the exponential rate of decline decreased, and dropped below the limits of detectability by days 11 - 14.

Cerium -144 (Figure 65) decreased nearly exponentially to day 3, then changed to a slower exponential rate of decrease. Only 1 - 3% of the original concentration remained at the end of the experiment.

Ninety percent of the original activity of Mn-54 and Ce-144 left the water by day 2, and 90% of Zn-65 was gone by day 4. The original activities of Ce-144, Ba-133, and Cs-137 were over 10 times as high as that of Mn-54 or Zn-65.

Barium -133 (Figure 66) had the slowest exponential rate of decline overall, and the exponential rate remained nearly constant after day 4. As a result of its slow removal from the water, about 25% of the original concentration remained on day 14.

Cesium -137 (Figure 67) was similar in pattern to Ce-144 but the exponential rates of decline were faster so less remained in the water by the end of the experiment (more than 5%).

None of the radionuclides reached equilibrium by day 14, except possibly Mn-54.

The ratios of radionuclides in the sand and animals to those in the water on day 14 are presented in Figures 68 - 70. The ratios could not be calculated for Zn-65 or Mn-54, since measurable amounts were not present in the water on day 14.

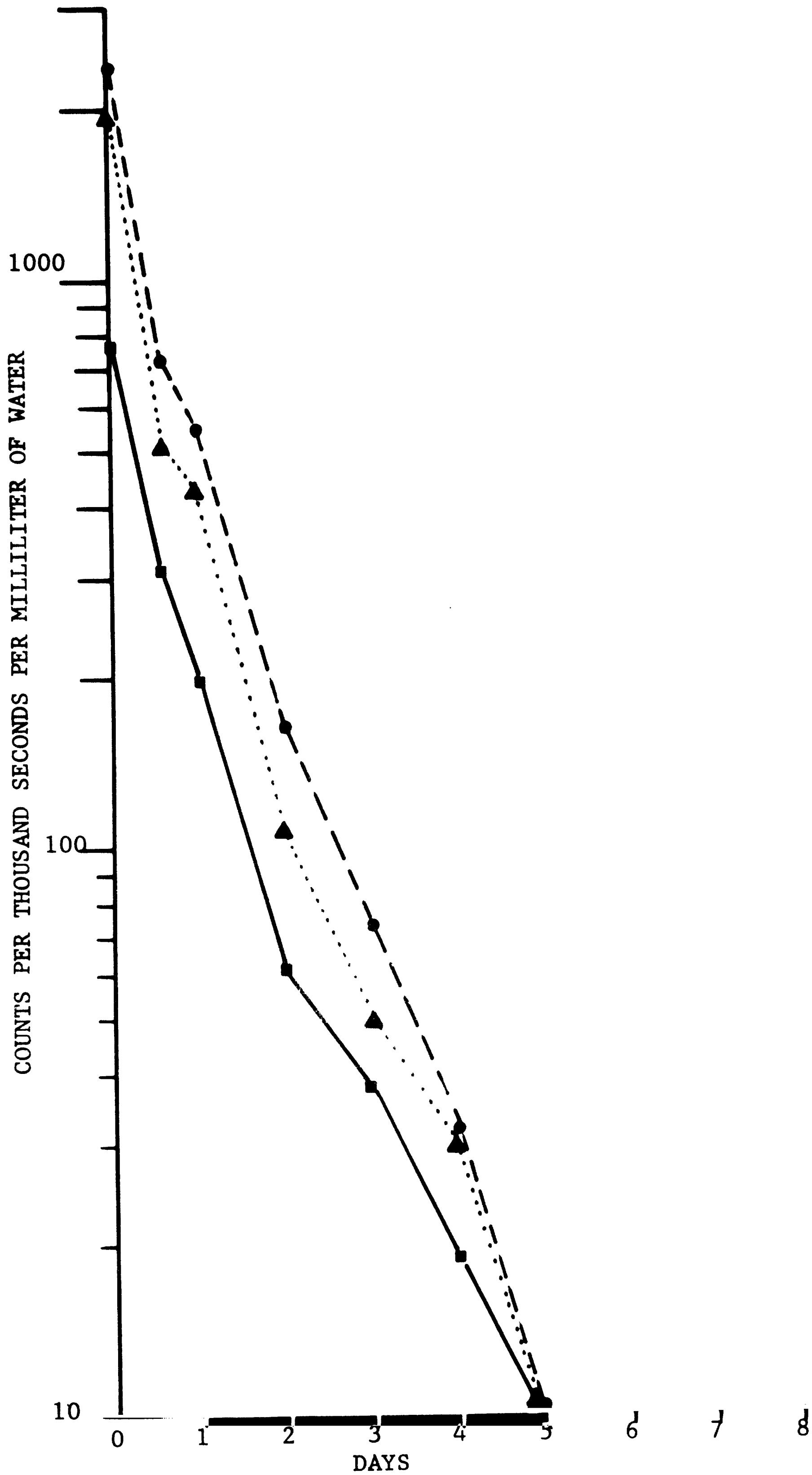


Figure 63. Manganese-54 in the water during the experiment. Dots = jar B; triangles = jar C; squares = jar A.

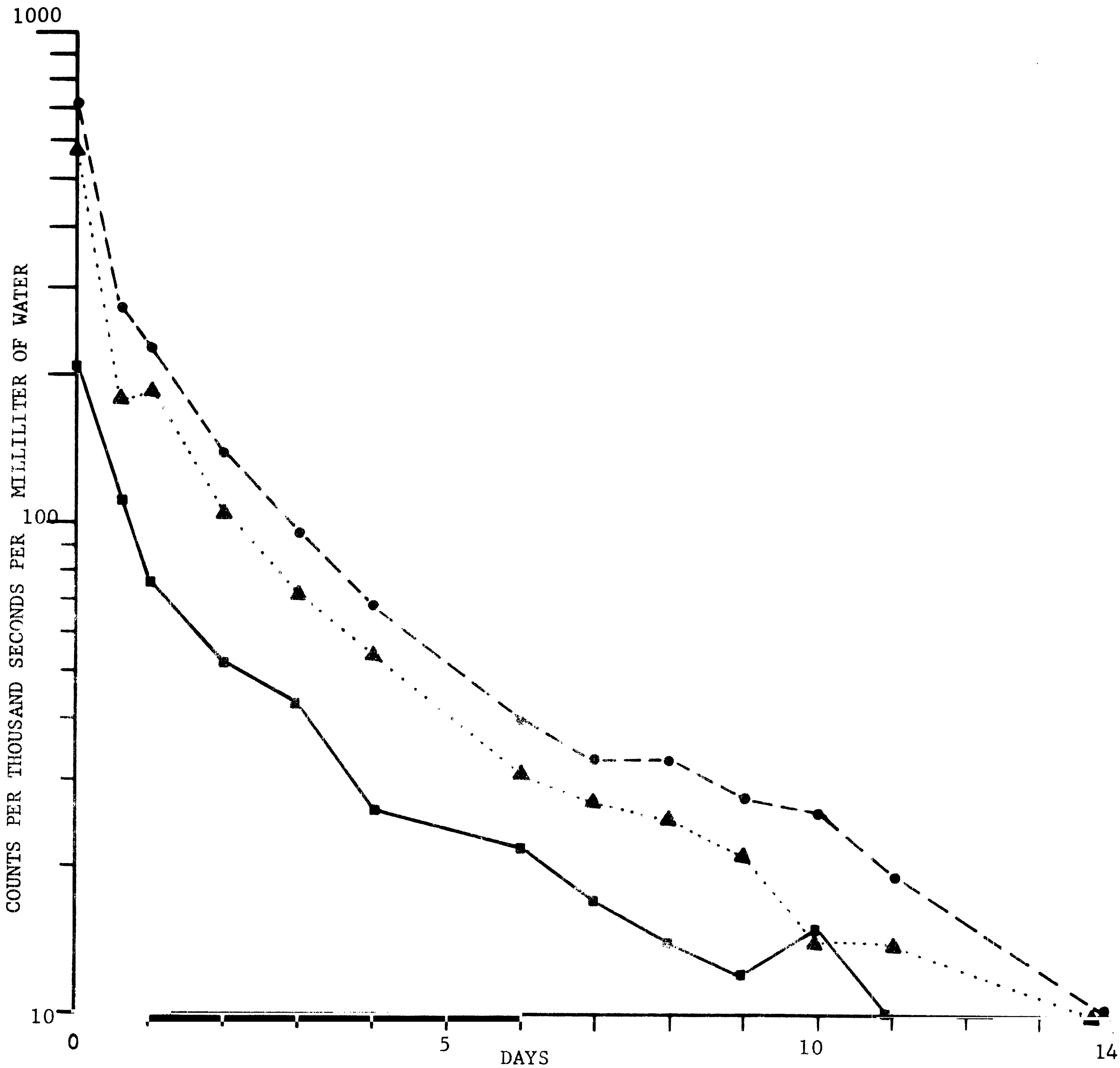


Figure 64. Zinc-65 in the water during the experiment. Dots = jar B; triangles = jar C; squares = jar A.

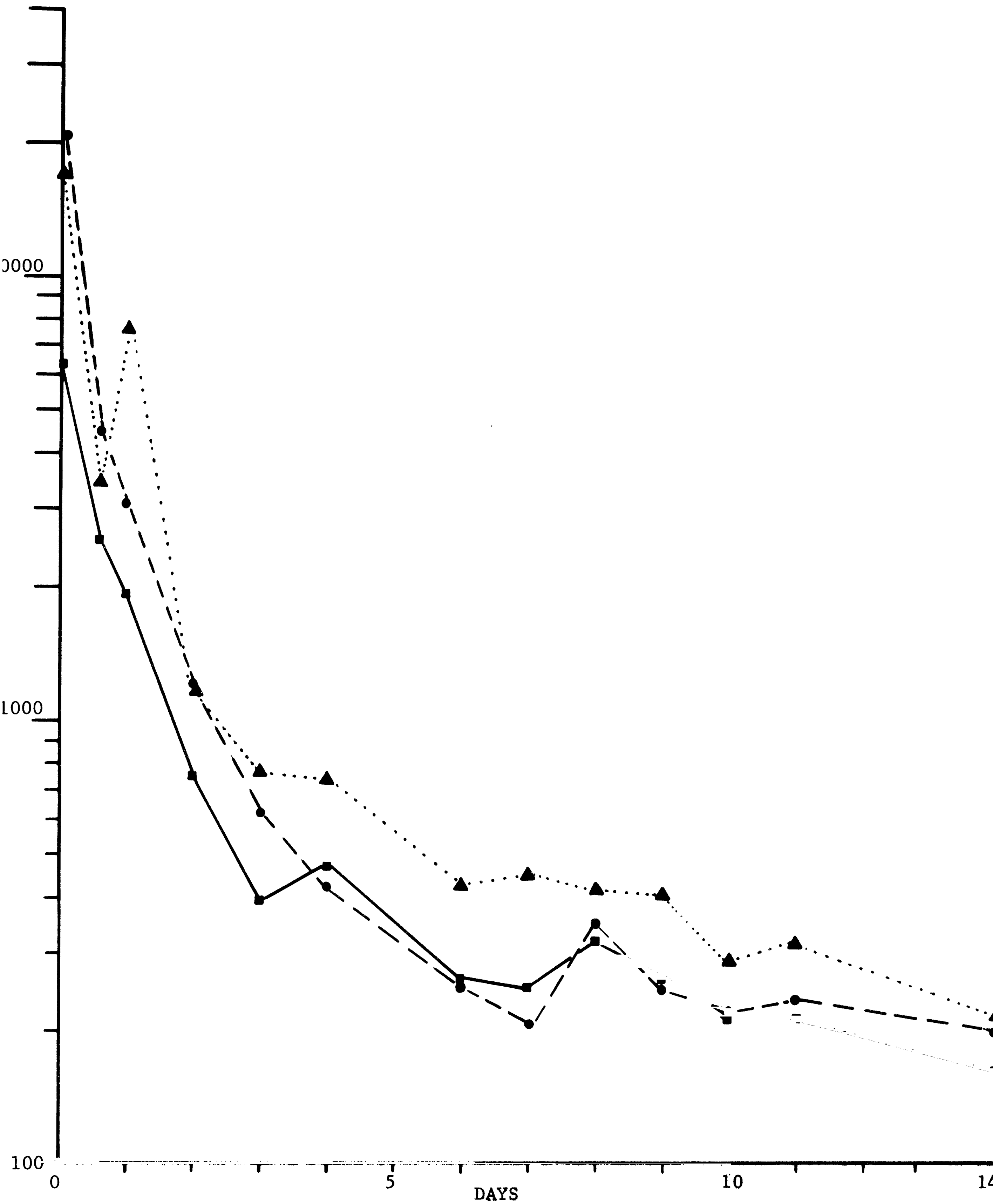


Figure 65. Cerium-144 in the water during the experiment. Dots = jar B; triangles = jar C; squares = jar A.

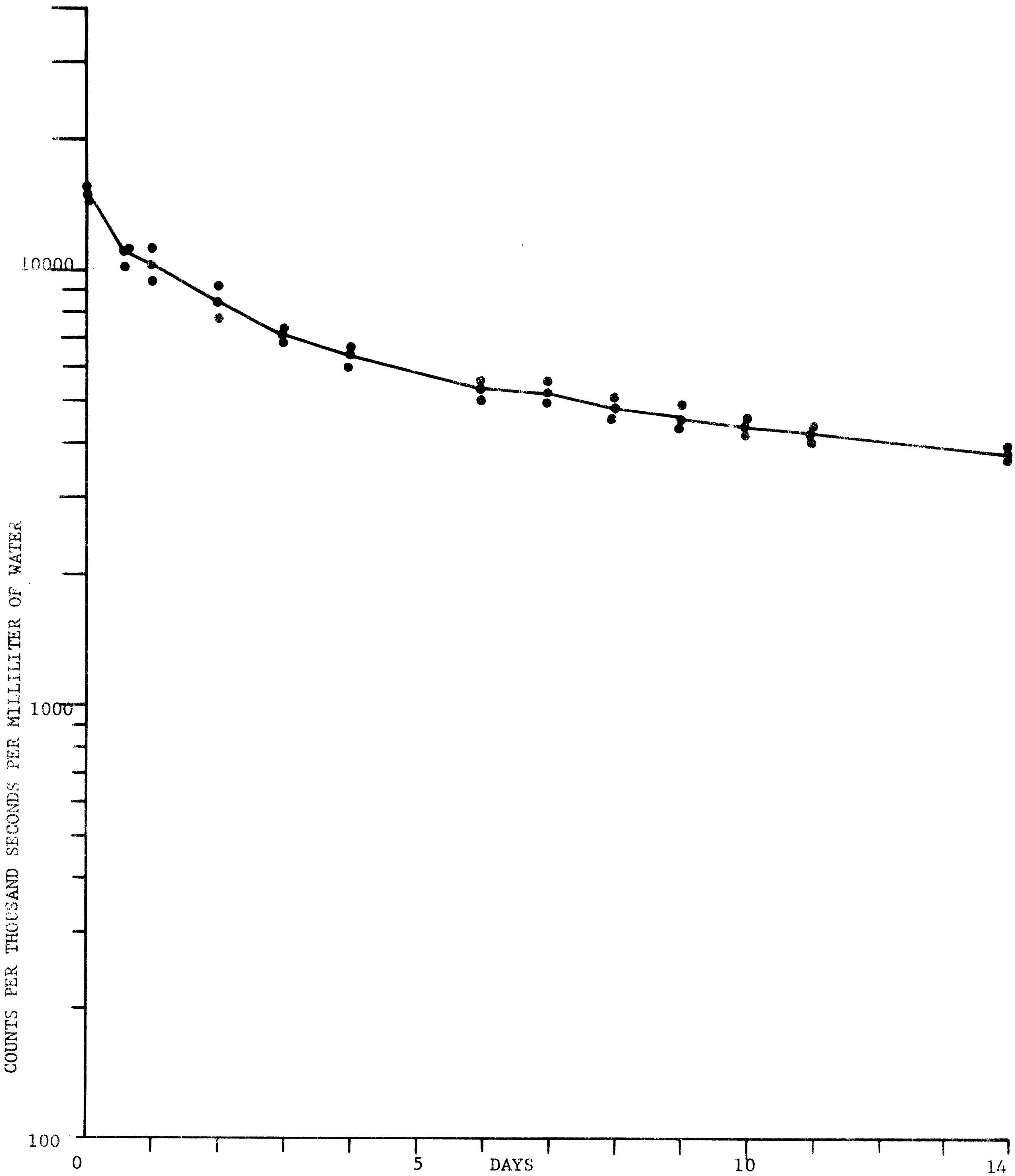


Figure 66. Barium-133 in the water during the experiment.

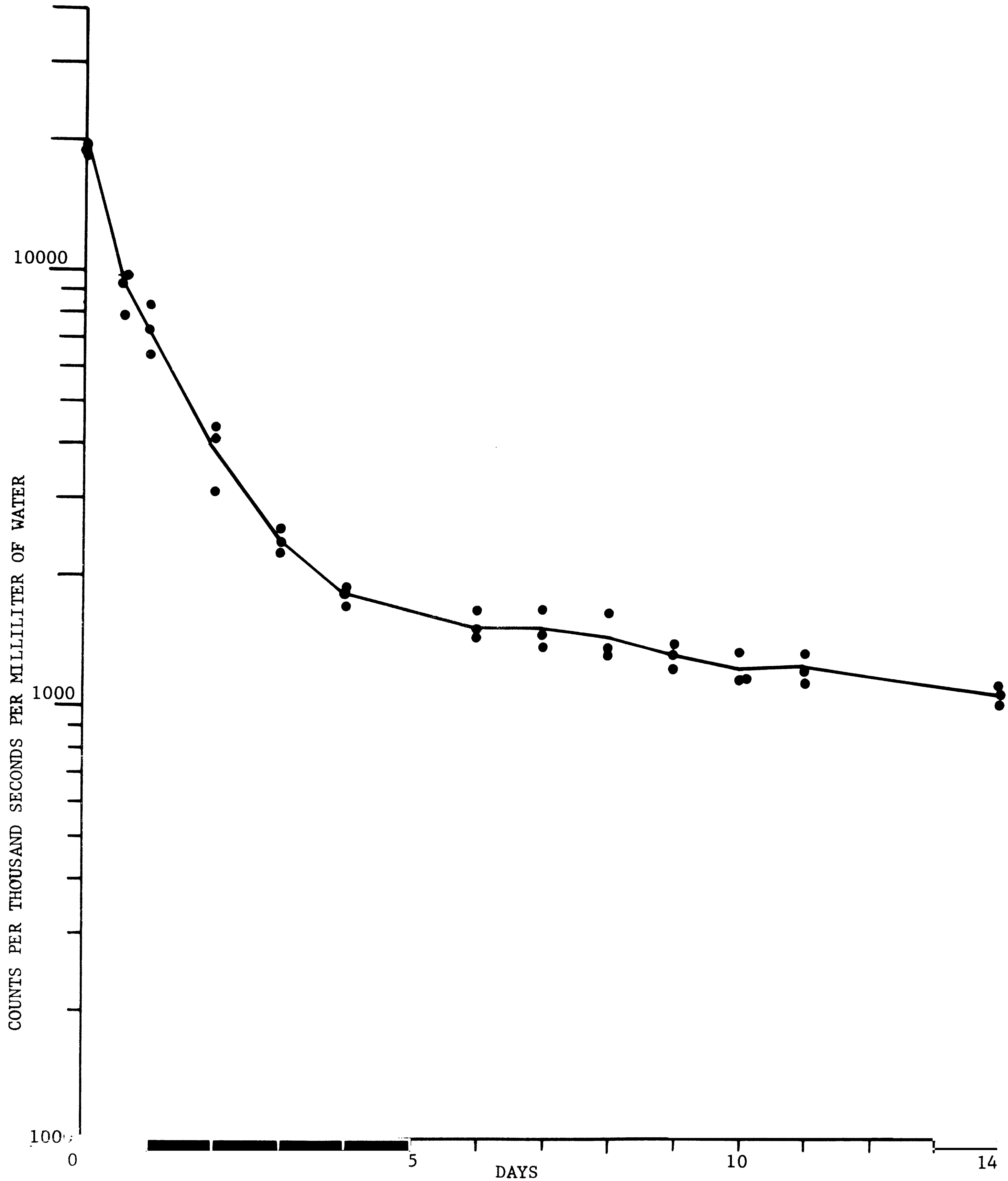


Figure 67. Cesium-137 in the water during the experiment.

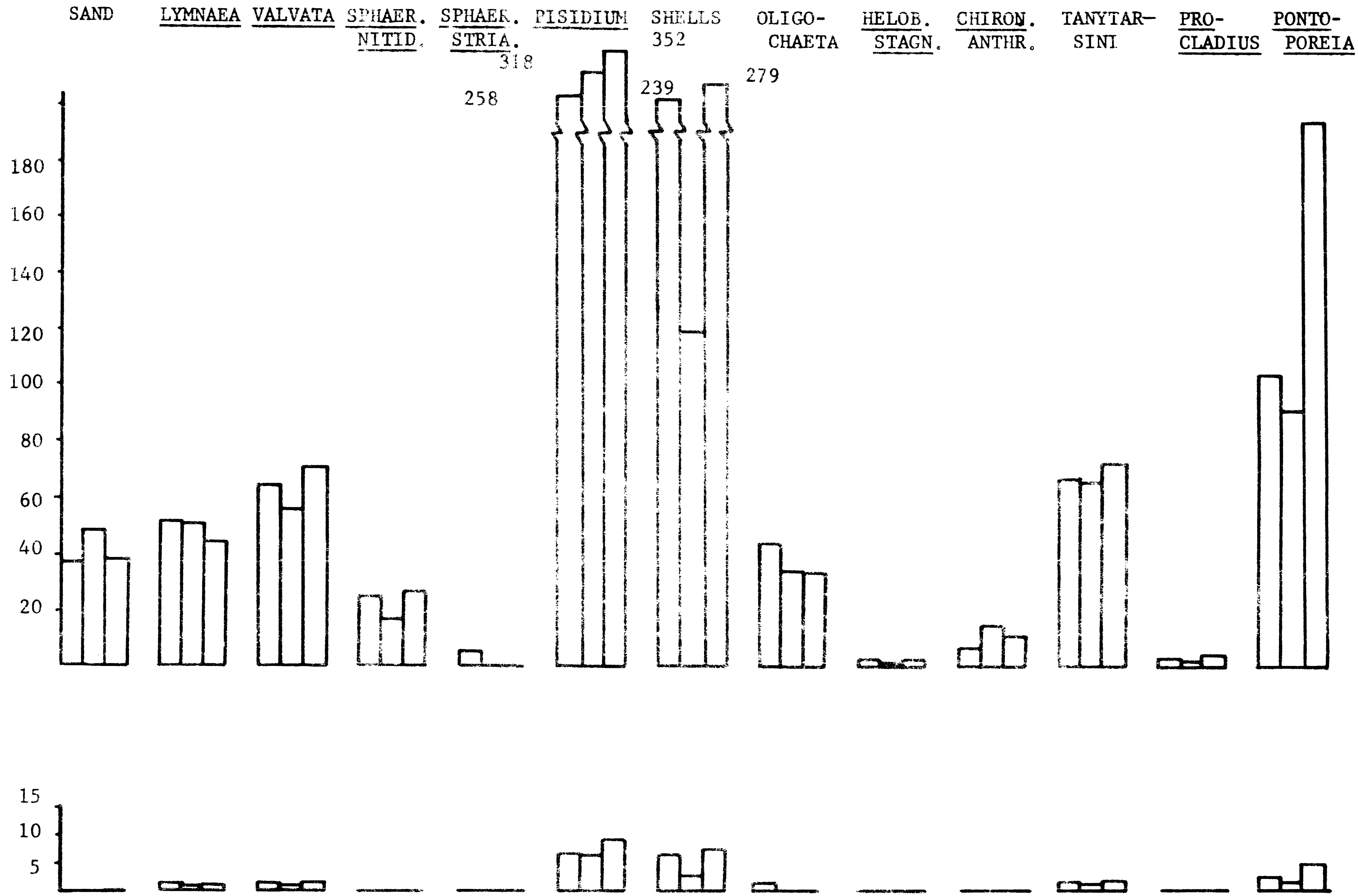


Figure 68. Concentration ratios for Ba-133. Upper histograms give ratios of counts per ml of sand or per g of animals vs. counts per ml of water on day 14. Lower histograms give ratios of counts per g of animals vs. counts per ml of sand. Contiguous bars represent the three replicate jars.

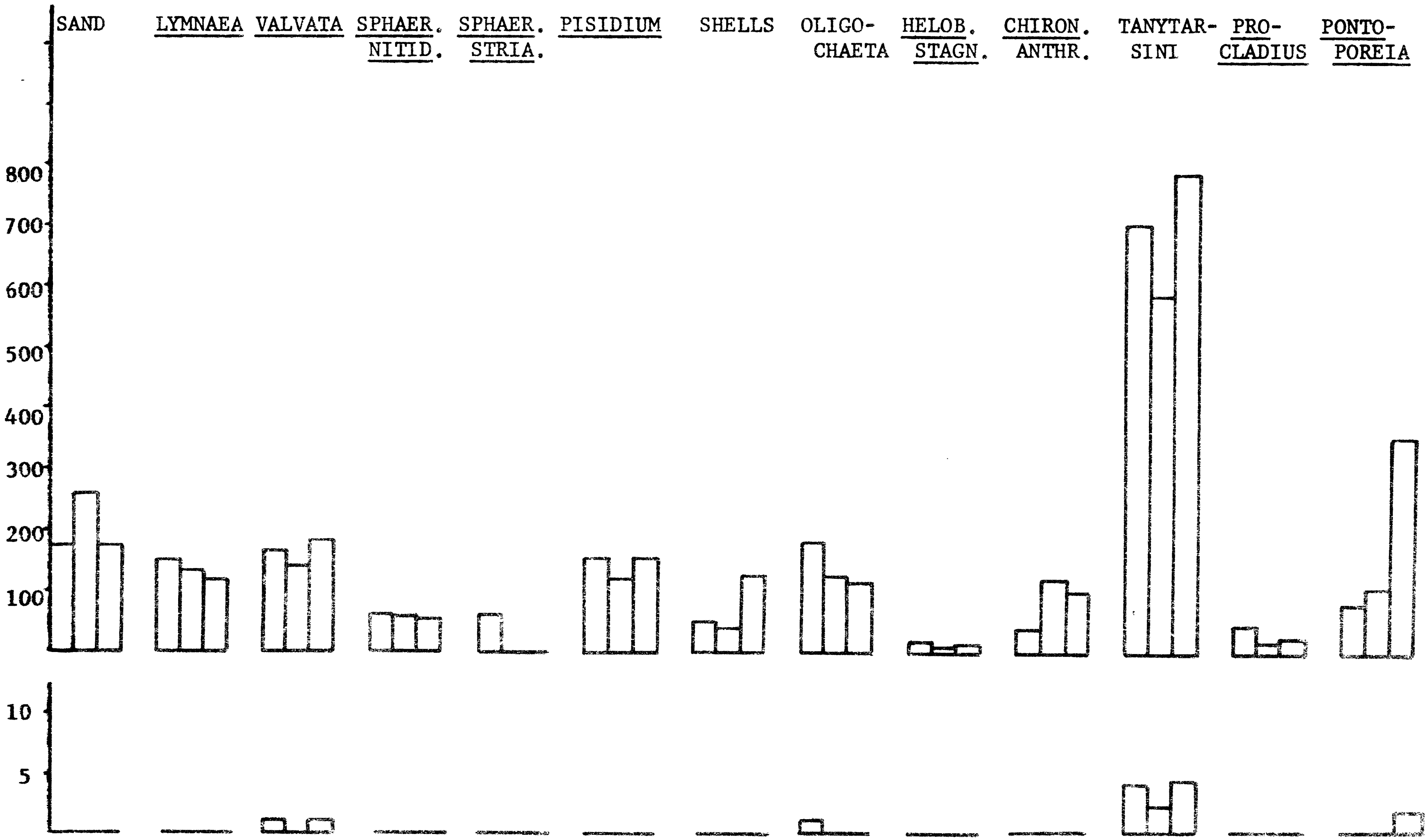


Figure 69. Concentration ratios for Cs-137. See fig. 68 for explanation of histograms.

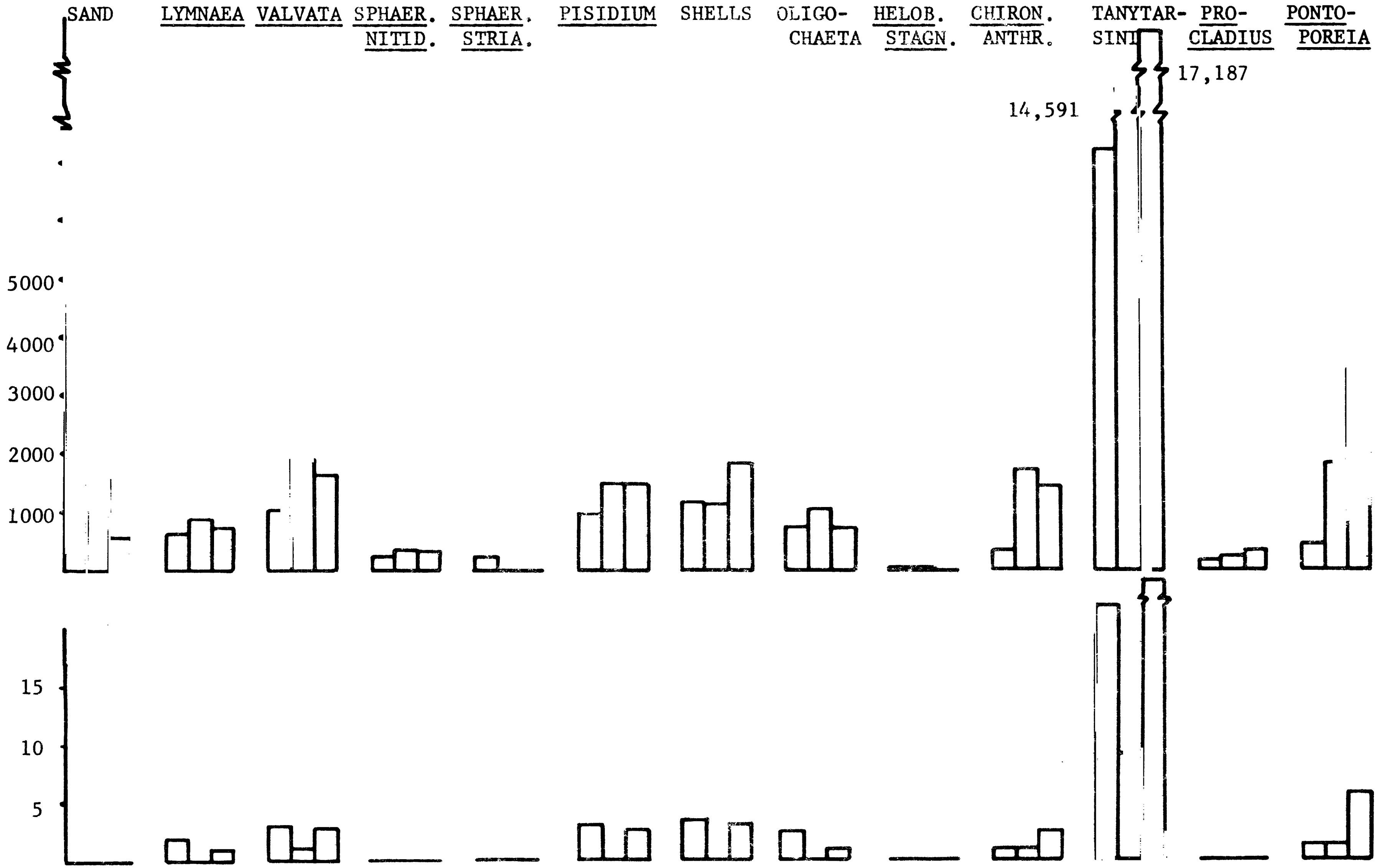


Figure 70. Concentration ratios for Ce-144. See fig. 68 for explanation of histograms.

Sphaerium striatinum, (fingernail clam), *Helobdella* (leech), and *Chironomus* and *Procladius* (dipteran larvae) were poor concentrators of Ba-133 (Figure 68). Sand, *Lymnaea*, *Valvata* (snails), *Sphaerium nitidum* (fingernail clam), Oligochaeta, and Tanytarsini (dipteran larvae) were better, with ratios between 20 and 80 to 1. Best were *Pisidium* (tiny fingernail clams), empty shells (including those of *Pisidium*, *S. nitidum*, *Valvata* and *Lymnaea*), and *Pontoporeia affinis* (freshwater shrimp). Variability among replicates was large for these three categories, especially for empty shells and *Pontoporeia*, but there was little variation in ratios from different jars among other taxa. The concentration ratios for Ba-133 were low in general compared to those for other isotopes.

Cs-137 (Figure 69) was barely accumulated by *Helobdella* and *Procladius*, and moderately concentrated by other taxa and sand (ratios mostly between 50 and 250 to 1.) *Pontoporeia* developed a ratio over 350:1 in jar C. The best concentrator overall was the Tanytarsini larva, with a ratio of around 700. These ratios were higher than those for Ba-133, but still rather low.

Ce-144 (Figure 70) was concentrated less well by the *Sphaeriums*, *Helobdella*, and *Procladius* (ratios less than 400:1), and best, again, by *Pontoporeia* in jar C and Tanytarsini. Extremely high concentration ratios were developed by Tanytarsini in jars B and C, in excess of 14,500:1. Other taxa and sand exhibited ratios between 500 and 2,000.

Ratios of the radioactivity per gram of animal to the amount per milliliter of sand are also illustrated in Figures 68 - 70, and in Figure 71 for Mn-54 and Zn-65. Only those taxa which were the best concentrators in comparison to the final concentration in the water developed ratios above 5:1 in relation to sand (see Table 61). For Ba-133 (Figure 68), these were *Pisidium*, empty shells, and *Pontoporeia*, in that order. Tanytarsini and some sets of *Pontoporeia*, *Valvata*, and Oligochaeta concentrated Cs-137 above the amount in the sand (Figure 69).

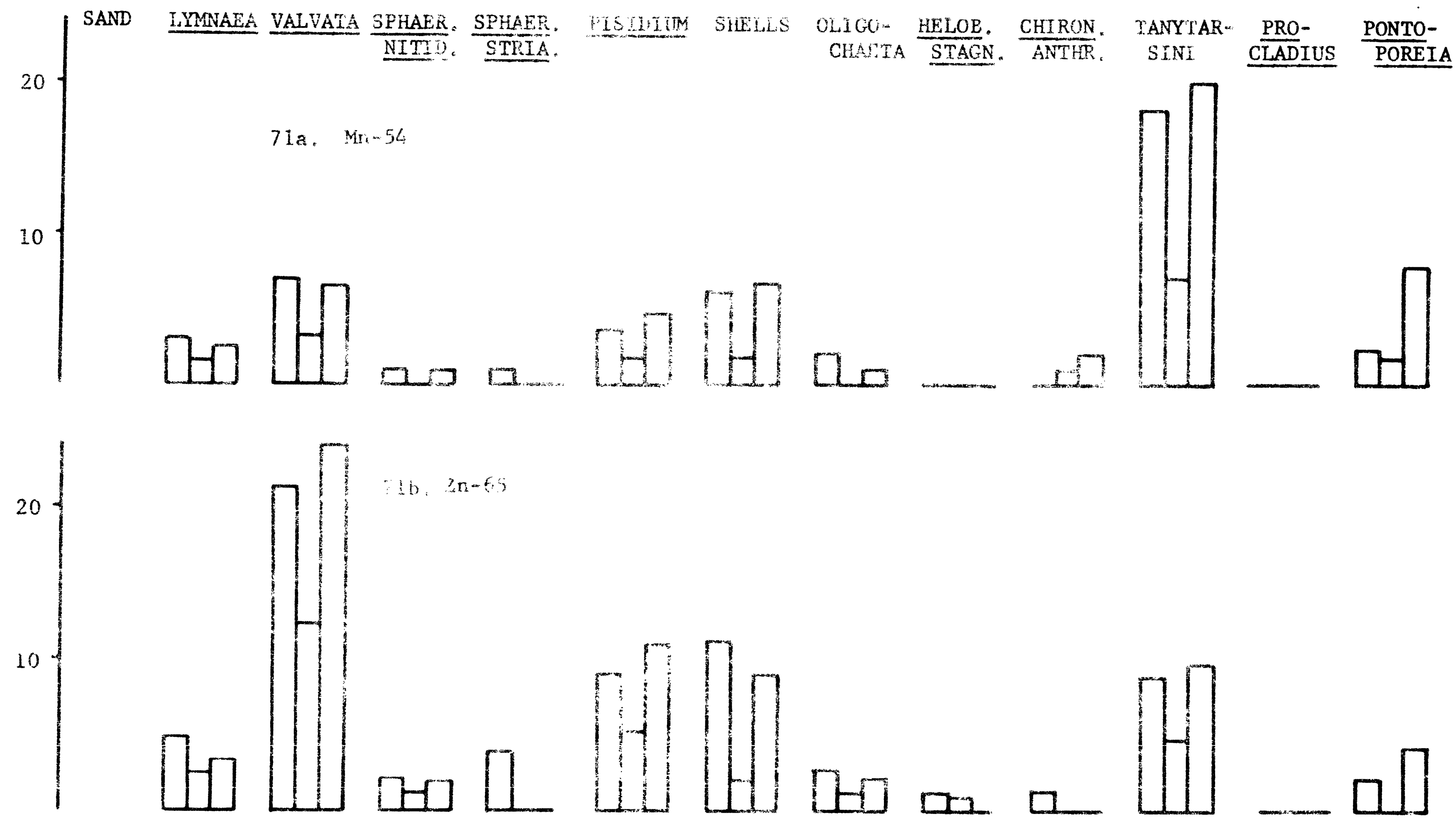


Figure 71. Concentration ratios for Mn-54 (upper histograms) and Zn-65 (lower histograms): counts per g of animal vs. counts per ml of sand on day 14. Contiguous bars represent the three replicate jars.

Table 61. Animals which concentrated each radionuclide in relation to sand by 5:1 or more. The third column is the number of replicates in which this criterion was met. The concentration ratios are listed in the fourth column.

Radionuclide	Animal	No. Repl.	Conc. Ratios
Ce-144	Tanytarsini sp.	3	22.5, 9.1, 29.3
	Pontoporeia affinis	1	5.9
Ba-133	*Pisidium* spp.	3	6.9, 6.5, 9.2
	Empty shells*	2	6.4, 7.3
	Pontoporeia affinis	1	5.1
Cs-137	none (2 replicates of Tanytarsini developed ratios over 4)		
Mn-54	*Valvata* spp.	2	7.2, 6.5
	Empty shells*	2	6.1, 6.7
	Tanytarsini sp.	3	18.3, 7.0, 20.0
	Pontoporeia affinis	1	7.9
Zn-65	*Valvata* spp.	3	21.3, 11.4, 24.0
	Pisidium spp.	3	9.0, 5.3, 11.1
	Empty shells*	2	11.2, 9.0
	Tanytarsini sp.	2	8.9, 9.7

*See text

More taxa were able to concentrate Ce-144 (Figure 70) above levels found in the sand, and Tanytarsini and *Pontoporeia* in jar C developed larger ratios than for Ba-133 or Cs-137. *Lymnaea*, *Valvata*, *Pisidium*, empty shells, Tanytarsini, and *Pontoporeia* all concentrated Mn-54 (Figure 71a) above levels found in the sand, but Tanytarsini clearly concentrated it most. All kinds of animals except *Procladius* developed higher Zn-65 radioactivity (Figure 71b) than the sand, but *Helobdella* and *Chironomus* just barely did so. *Pisidium*, empty shells and Tanytarsini concentrated moderate amounts, and produced ratios of 2 - 11 to 1 over sand. *Valvata* was the most effective concentrator, however, with a ratio of 24:1 in one replicate. Only the concentration of Ce-144 by Tanytarsini exceeded this ratio.

Discussion

The sizes and kinds of animals subjected to radionuclide solutions were less than ideal in some respects. Kidd (1970) provides data which indicate a highly significant difference between uptake by small and large *Pontoporeia affinis* for Sr-85, Mn-54, and Zn-65. Insufficient material was available in the present experiment to test both small and large individuals of *Pontoporeia* separately. The experimental sets of animals did include a few large animals along with the small ones, however. The presence of several more large animals in jar C than in the other jars could account for the elevated uptake in that jar. The lone *Sphaerium striatinum* in jar A cannot have provided adequate information about the uptake of this species.

The deaths of large proportions of both *Pontoporeia* and *Sphaerium nitidum* indicate that uptake conditions may not have been ideal for these species. The route from dissolved ions through phytoplankton to filter-feeding benthos was not present in this system, but it could be a very important one. Suspended

particulate organic sources of radionuclides would probably have increased the uptake by all the sphaeriids (fingernail clams), *Chironomus*, Tanytarsini, and *Pontoporeia*. Kidd (1970) found that radionuclides in the form of dead algal cells were much more readily taken up by *Pontoporeia* than those in the dissolved state. Nevertheless, considerable uptake occurred in several species, and some kinds of animals appeared to thrive in the jars.

The complete removal of flesh from dead mollusks, and rapid disappearance of the dead *Mysis* indicated that very active predators or scavengers occurred among the animals in the jars. Only *Procladius* and *Helobdella* are definite predators, however, and their accumulation of radionuclides was much less than other kinds of animals. Perhaps the snails or Tanytarsini fed on decaying flesh.

The patterns of disappearance of radionuclides from the water suggest that several processes occurred during the experiment. Ce-144 had the most complex pattern. This element is not very soluble in water, especially at pH's near neutrality. Its low ionic concentration could have led to the formation of particles with a wide range of sizes. Immediate precipitation of larger particles would then have removed much of the radioactivity due to this isotope, and persistence of colloidal particles in uneven suspension could have produced some of the irregularities in its rate of decline and differences in rank order of the three jars. The final, slow rate of exponential decline could be due to uptake by adsorption on the glass and sand and incorporation into animals and microbes growing at the water-solids interfaces. Some form of co-precipitation with Cerium or other particles which formed as a result of changes in pH and salinity could explain the initially rapid decreases in all of the elements. The later slower rates of decline are attributable to processes similar to those which were described for Cerium, as well as to the normal move-

ment toward chemical equilibrium with other isotopes of the elements in the system. The complete and rapid disappearance of Mn-54 over five days suggests that some active accumulatory process for this element existed in the jars. Manganese (and iron) typically form encrustations on sand grains and some sphaeriid shells which, in some parts of Lake Michigan, develop into manganese nodules. These encrustations have a high affinity for other ions, so this process may account for much of the removal of radionuclides from solution, and for the high concentrations in sand and clams. Whether it is a purely geochemical process, or involves bacteria or fungi has not been established.

Zinc was concentrated to higher levels by more kinds of animals than other isotopes. Its concentration by marine organisms is well known, and Kidd (1970) previously observed that *Pontoporeia* concentrates it.

In general, the tendency of a radionuclide to remain dissolved or suspended in the water was negatively correlated with the tendency of benthos to accumulate it to higher levels than occurred in the sand. Even though large amounts of barium and cesium were present in the sand, few animals concentrated these elements further.

Those kinds of animals which accumulated the most radionuclides are believed to feed upon settled, fine detritus and microbes growing on solid surfaces. The snails grazed the glass walls of the jar. They probably took up more radionuclides in the jars than they would in the lake, because of the special surface provided by the glass for adsorption of radionuclides. *Pontoporeia* is believed to feed on detritus filtered from the water or stirred up from the superficial sediments. Tanytarsini build tubes which lie on the surface of the sand, and pump water through them constantly. They probably eat fine particles which become entrapped in the mucus with which they line their tubes, or they may scrape surface growths from the sand grains. The *Sphaerium*

nitidum may have fed less than normally, because of elevated temperatures, so in the lake they might take up more radionuclides. The Oligochaeta feed below the surface of the sediments, away from the highest levels of radioactivity. Their uptake may have been suppressed in the experiments because of the intentionally coarse grain size of the sediments -- ordinarily they prefer silt and clay-sized material. The weak uptake by predators indicates they were not feeding during the experiment.

A considered recommendation of the relative usefulness of these kinds of animals as biological monitors of radionuclides must incorporate the availability of the animal in the environment, i. e., the constancy of its populations and its abundance in the vicinity of the outfall.

No animal is very abundant near the outfall. A mixture of Chironomidae and low numbers of *Pontoporeia*, Oligochaeta, *Pisidium*, and *Sphaerium striatinum* characterize the benthos at depths from 6 - 10 meters. The Chironomidae have the disadvantage of being difficult to collect in large numbers because of their small size and burrowing habits, and they are so small for much of the year that efficient collection is practically impossible. Sphaeriidae, Gastropoda, and *Pontoporeia* are easier to collect, for they can be stirred out of the sediments and washed clean of sand in a relatively simple epibenthic sled bearing a coarsely meshed net. Large amounts of material can be collected, even at the depth of the outfall, with such a sled. Therefore, even though one chironomid (and not a very abundant species, at that) accumulated many radionuclides very efficiently, *Pontoporeia* is much better as a radionuclide monitor. This amphipod was frequently among the better accumulators in this experiment. Some variability in its concentration ability is to be expected in seasons when its population size distributions are large (as in spring) or small (as in summer). Other kinds of animals should not be ignored completely,

however. Chironomidae may still be used for accumulation studies, at certain times of the year, such as late summer and autumn when *Pontoporeia* is small. *Pisidium* accumulated barium better than most animals.

The affinities of different animals for different radionuclides in this experiment strongly indicates that at least three or four kinds of animals be monitored. These should include *Pisidium*, Gastropoda, Tanytarsini (or other small Chironomidae) and especially *Pontoporeia*.

This experiment also illustrates the tendency of sand to accumulate radionuclides. The sediments themselves may be the best overall monitors of radionuclide occurrence in the environment, and they should certainly be collected for measurements.

Finally, this experiment leaves some important questions unanswered. If radionuclides are released intermittently, and exposure of animals is at high levels for brief periods, some of the radionuclides may dissipate back into the water from benthos and sediments after the "slug" of radioactive water passes. The stability of accumulated radionuclide concentrations in the animals should be determined. Some elements which are abundant as radioisotopes in nuclear power plant wastes, and which may be concentrated by plants and animals, are Cobalt, Chromium, and Iodine. These should also be studied.

For a more detailed discussion of the uptake of Zn, Sr, and Mn by *Pontoporeia*, refer to Kidd (1970).

References

Kidd, C. C. 1970. Benton Harbor power plant limnological studies. Part IV. *Pontoporeia affinis* (Crustacea, Amphipoda) as a monitor of radionuclides released to Lake Michigan. Spec. Rep. No. 44, Great Lakes Res. Div., U. Michigan. 71 p.